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READABLE SCHOOL CHEMISTRY

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READABLE SCHOOL CHEMISTRY

A BOOK FOR BEGINNERS

BY

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SENIOR CHEMISTRY MASTER IN WOODHOUSE SECONDARY
SCHOOL, SHEFFIELD



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P R E F A C E

ALTHOUGH, in recent years, the output of scientific literature, both popular and otherwise, has been very large, the pupil who has just begun a systematic study of science has not been catered for. There are few, if any, scientific books which a pupil with only a rudimentary knowledge of physics and chemistry can profitably read right through. Sooner or later he will encounter difficulties arising from his lack of knowledge and experience. Popular books, in pursuit of their object, skim the theoretical parts of the subject and roam extensively over the field of science; text-books, on the other hand, emphasise the theory, which it is their function to do, and, as a rule, neglect the human side.

The present little book deals historically, and to a certain extent popularly, with the ground usually covered in a first year's course of chemistry. It has been written with a view to supplementing the practical work in the laboratory; each section should naturally be read *after* the corresponding series of experiments have been performed, so that the valuable training in scientific method may not be lost by previous knowledge of the results of the experiments. The method of treatment serves two

useful purposes ; it creates an interest in chemical theory by humanising it, and it indirectly inculcates the principles of scientific method by tracing the steps by which the theories were established. When the pupil's interest has been thus obtained, and the correct mental attitude induced, he will have less difficulty in remembering the facts. Few teachers of elementary chemistry will work through a course which includes a study of air and water without making some reference, however brief, to Priestley, Scheele, Lavoisier, and Cavendish, but the time allowed for science in most schools does not permit of a full treatment of this aspect of the subject. For this reason, it is hoped that the book will prove useful by giving in a readily accessible form information which is not only interesting but mentally stimulating.

I am indebted to my friends Messrs. R. B. Lyall, M.A., Wm. Douglas, M.A., and N. M. Johnson, B.Sc., for valued suggestions and assistance in proof-reading.

J. A. C

PREFACE TO THE SECOND EDITION

A NUMBER of Revision Questions and typical Numerical Exercises on the work covered by the book have now been inserted at the end. It is hoped that these will increase the usefulness of the book. My thanks are due to my colleague, Mr. A. Fraser, who kindly undertook the laborious task of working through the Numerical Exercises and checking the answers.

J. A. C.

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READABLE SCHOOL CHEMISTRY

CHAPTER I INTRODUCTION

Man's Curiosity.

Curiosity is a very noticeable characteristic of childhood ; the awkward questions that children ask are a constant source of amusement, and sometimes of irritation, to their parents, and are retailed for the benefit of the general public in the joke columns of newspapers and periodicals. In many cases, curiosity is carried a step further than merely asking questions ; children will pull their toys to pieces just to see what they are made of, or how they work. In doing so, they are not altogether blameworthy, as they are often led to believe ; they are really exhibiting the scientific spirit in a crude form. Curiosity has been one of man's characteristics all down the ages, and it has been responsible for all the inventions and discoveries that have ever been made. By continually asking questions such as : How did this come about ? Why does this happen ? What is this made of ? man has gradually acquired a knowledge of the wonders of nature, and has been enabled to use the forces of nature for his own ends.

What is Chemistry ?

The boy who takes his toy to pieces to see what it is made of is doing what the chemist does to the many substances that go to make our earth. Chemistry is that

branch of science in which we try to find out what things are made of, and try to build up new substances with those we already know. Now this process of inquiring into the composition of substances has been going on for thousands of years, and the amount of knowledge that has accumulated is almost appalling ; so great is it, that now no one mind can possibly contain it all. Even those who devote a lifetime to the study of chemistry do not pretend to master more than a fraction of the subject. It is possible, however, for the ordinary person to learn much that is of great interest about the subject without devoting a disproportionate amount of time to it, and, what is perhaps more important, to learn something about the method and spirit of science.

How Chemistry began.

From the very nature of chemistry, it will be easily understood that, for its origin, we must go back to very early times. As a matter of fact, we have to go back to a period which is so remote that hardly a trace of it has come down to us. Whenever man appeared on the earth, his innate curiosity would be aroused by all the interesting things that were going on around him. His brain would get to work, and he would begin to inquire into these things ; as a result of his inquiries, assisted by accidental discoveries, he would gradually acquire a knowledge of Nature and her ways. At first, man's brain was inexperienced, and his knowledge increased very slowly. He fell into many errors and came to wrong conclusions, some of which were corrected almost immediately, some of which persisted for a long time. Nevertheless, it is surprising to find how much progress our early ancestors made. Certainly their discoveries were often made in haphazard fashion, but they laid the foundations on which chemistry was reared.

How Science should be studied.

While we must seek the origin of chemistry in pre-historic times, as a true science it is only about two hundred years old. It was only during the eighteenth century that chemists fully realised that science must be studied quantitatively, that is, that they must measure the quantities of the different substances used in their experiments. Much of the success of the outstanding men in the history of chemistry was due to their recognition of the importance of the balance, and the chief reason for the slow progress of chemistry before the eighteenth century was the fact

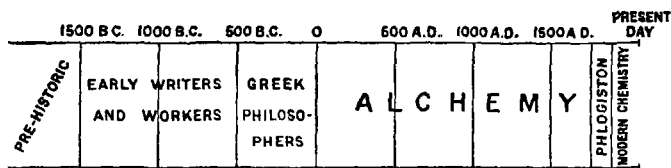


FIG. 1.—This chart will make clear to the reader the comparative length of the periods into which the history of chemistry is usually divided. It must be remembered that these divisions are only approximate.

that the balance was not always regarded as a necessary part of the equipment of chemical laboratories. In the early days of science, the philosophers (they can hardly be called scientists) formed their own ideas of things, and in some cases manipulated the facts so that they might fit in with their own ideas. To give one example, we find a Greek, Aristotle by name, stating that a pot filled with ashes can hold as much water as an empty one of the same size! For some reason or other he thought this should be the case, and stated that it was so. Now science must be studied in exactly the opposite manner; our ideas must be the result of a study of the facts, and we are not justified in making a statement that cannot be proved by experiment.

Scientific Method.

It may here be advisable to state in a few words the method by which scientific laws are established. The process consists of three steps: (1) a number of experiments are performed, each bearing on the particular subject under investigation, or it may be that certain observations are made which appear to have something in common; (2) the results of all these experiments or observations are compared, and a general statement, or law, is made which will include all these particular results; (3) the truth of the law is tested by further experiments. This, in brief, is what has come to be called the scientific method.

In practice, it works out something like this. A certain investigator, as a result of a few experiments, notices something common to all of them. For example, Archimedes, on weighing several bodies in air and in water, noticed that the apparent loss in weight was equal to the weight of water which the body displaced. He was not justified, however, in saying that that was a general rule; it might have just happened to be true in the particular experiments he performed. He had to repeat the experiment many times using solids of different material, shape, and size before he was able to state confidently that the law always held good as far as his experience went.

Science is not concerned with men's preconceived ideas on a subject; all it wants is the truth. If a particular fact is not in accordance with a certain law, then it is not the fact that is wrong, but the law. We cannot alter facts, but we can alter our ideas about them, and we must do so if the facts demand it. It therefore behoves the beginner to discard all preconceived notions about the subject to be studied, and to build up his ideas from the facts he observes. It will be seen in the following pages that the failure on the part of some men to look facts squarely in the face led

them away from the truth into bypaths from which some never returned. They often approached the study of chemistry with a fixed idea in their minds, when their minds should have been open to receive what was presented to them.

CHAPTER II

EARLY CHEMISTRY

Birthplace of Chemistry.

Authorities differ as to the derivation of the word "chemistry," but it appears that it probably comes from the Egyptian word *khemet*, meaning dark or black. In the seventh century A.D., the Arabs conquered Egypt, and found that Egyptian philosophers practised a curious art which they kept strictly secret from the common people. They posed as magicians and pretended to be able to perform miracles. The story of the Ten Plagues in Egypt which is recorded in the Old Testament is well known. We are told that, during that time of pestilence, Pharaoh the king consulted his wise men and magicians, but that they had to confess that they were powerless to stop the plagues. Those wise men were the early chemists in whom reposed all the knowledge that had been handed down from generation to generation. When the Arabs came, however, they learned many of the secrets which these men had guarded so jealously, and, along with the knowledge they had acquired from the Greeks, spread them over the whole of civilised Europe. In the records of that period which have been preserved, it is found that the name *Alchemy* was applied to the art of the Egyptian philosophers. *Al* is the Arabic definite article, and *khem* means dark or black, so the Arabs christened it *The Black Art*, because of the secrecy which its devotees had maintained. It is probable, however, that the explanation is more

literal. Egypt was sometimes called the Black Country, because of the fact that, when the Nile overflowed its banks, it left the land on either side of it covered with a black mud. Alchemy may therefore mean The Art of the Black Country.

Although the Egyptians of five or six thousand years ago practised alchemy, there is evidence that even they were not the originators of it. Certain facts go to show that the Chaldeans at a still earlier period knew many of the substances and processes of alchemy. There is no written record of this period, so we do not know very much about it. What is known has been discovered as a result of excavations among the ruins of ancient Chaldean cities.

Knowledge possessed by the Ancients.

In later times, when the Egyptians took up the art, we have more evidence to go upon, for by this time men had learned to record their knowledge in writing, not on paper, but on stone tablets. Many of these "documents" have come to light, from which we learn what substances and processes were known, and from crude drawings, what apparatus was used. The ancient alchemists knew how to extract certain metals from their ores, to prepare certain drugs, to make glass and soap, and to dye cloth. It is thus seen that their accomplishments were of no mean order considering the period in which they lived. Certainly they did valuable pioneer work.

The Greek Philosophers.

During the five hundred years immediately preceding the Christian Era, the centre of the world's learning was in Greece. During this time there lived in Greece men whose philosophical writings are even now read with the greatest of interest. The Greeks, however, were philosophers, not

scientists. They spun their ideas of the universe from their own imagination instead of from observation and experiment, with the almost inevitable result that they fell into many errors, and made statements which were contrary to fact. They added very little to the progress of science; on the contrary, they hindered progress, because they were so much revered that their statements were taken for granted without being verified.

The Perfect Metal.

In the history of all science, and more especially of that branch of science we are now studying, it is very noticeable that progress was often delayed by the prevalence of a wrong idea. This happened, not once, but several times in the history of chemistry. Perhaps it was a result of the speculations of the Greeks, or perhaps it was a bold idea of some early alchemist, that the belief gradually came to be held that all metals could be changed into gold. It was said that metals grew in the same way as plants, and some misleading evidence was brought forward to prove that Nature in her great laboratory caused the base metals to grow until they were transformed into gold, which was regarded as the perfect metal. Would it not be possible to imitate and improve upon nature's process, and so have the power of quickly transforming all metals into gold? The idea held out so great hopes of personal enrichment, that the task of trying to make gold out of the less precious metals was eagerly undertaken by generation after generation of alchemists; but at the end of fifteen centuries of diligent and exhaustive work, they had not produced a single ounce of gold out of another metal. Evidently, even in this twentieth century, men have not given up hope of being able to make gold artificially. As these lines are being written, it is announced that, in Germany, a process has been discovered by which gold can be

manufactured from other substances, but naturally no details are given !

The Philosopher's Stone.

The alchemists thought that the secret of the process by which metals were changed into gold lay in a certain substance which was called by various names, but which was usually known as the philosopher's stone. A few grains of this substance, they said, added to a molten metal at once produced pure gold. Hence it was that for centuries all the energies of the alchemists were devoted to the search for this philosopher's stone, the mystical substance that would make its discoverer rich beyond his wildest dreams.

As the search proceeded, this wonderful substance acquired many new properties ; it was said to prolong life, to cure disease, to raise the dead, to make the old young, to turn the coward into a hero, and to sober the drunkard. One would think that the very multiplicity of its properties would have raised the suspicions of the alchemists that it was merely a figment of the imagination ; but no, it seemed the more to stimulate their zeal, and to urge them on to greater effort and sacrifice. Had the alchemists' energy been directed into other channels, the history of chemistry might have been very different.

Many and wonderful were the recipes that were given by alchemists from time to time for the preparation of the philosopher's stone. Most of them are quite unintelligible, and were so even when they were written. Many claimed to have found the mysterious substance, but none of the discoverers described its preparation in straightforward language, for the simple reason that their claims were utterly unfounded. Nearly every known substance was used as an ingredient in the complicated preparations that were made in the course of the long search. The ardent

seekers mixed, heated, dissolved, distilled, tried every known process in the vain hope of producing this miraculous substance. The search, as has been said, lasted for many centuries, in fact, it was not till the middle of the seventeenth century that it was finally given up; and though in the course of their many experiments the alchemists made real discoveries, they did not realise the importance of them because their gaze was fixed on an unattainable goal. Yet it is not wise to use the word "impossible" in science; what seems impossible to-day may be shown to be possible to-morrow. In recent years many new and

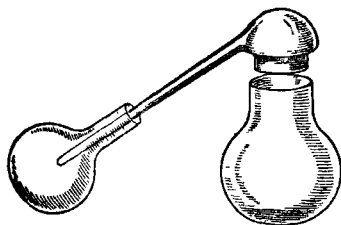


FIG. 2.—Alembic and Receiver used by Alchemists for distilling.

marvellous facts have come to light in connection with radium, X-rays, etc., which indicate that after all the idea that one metal may be changed into another is not so fantastic as at one time appeared.

Paracelsus.

During the latter part of the period we are now considering, the object of chemistry was changed. Up till the beginning of the sixteenth century, the central aim had been to change all metals into gold. Now, it was declared, the chief object of chemistry should be to cure disease—the alchemists should prepare medicines instead of looking for the philosopher's stone. From this, it was

but a step to the idea of a universal medicine, one that would cure any ailment. Instead of the elusive philosopher's stone, some alchemists began to search for an equally elusive *elixir vitæ*. The idea of a universal medicine had occurred to the minds of alchemists long before this, but it was usually associated with the philosopher's stone, though it is not very clear sometimes whether they were searching for two things, or for one with the double property of changing metals into gold and curing all diseases. The man who suggested that the chief aim of the alchemist should be the curing of disease was Paracelsus, a native of Switzerland who lived in the first half of the sixteenth century. He was the son of a physician, and had thus an early bias toward the study of medicine. He was a man of originality, and held strong opinions which he was not afraid to express, even though he made enemies by doing so. Because he departed from the aims and methods of his predecessors and struck out on entirely new lines, he has been called the "Luther of Medicine." It is interesting to note that these two reformers were contemporaries, and that while Paracelsus took no active part in the Lutheran reformation, he was entirely in sympathy with it.

By this change of aim alchemy became merely a part of medicine, but a science with such possibilities could not long remain in a secondary position. Modern chemistry may be said to have begun about the middle of the seventeenth century, though it was a century later before it was put on a sound footing. The hopeless search for a miraculous but imaginary substance was then definitely abandoned, and the science was brought out into the light of day, instead of being the secret of a comparatively few recluses. Men began to study nature for the sake of knowledge alone, and not from any ulterior motive of personal gain.

•

Alchemy.

A historian of science has thus described this alchemical period: "The period from the thirteenth to the sixteenth century was the golden age of alchemy, which was eagerly pursued by ecclesiastics as well as by others, and could reckon among its adepts bishops and kings—and even a pope! The pursuit of the two grand objects of alchemy, the transmutation of the common metals into gold, and the discovery of the universal elixir, became with many a passion to which time, money, and health were prodigally sacrificed. Disappointment and failure could not damp the ardour of the alchemist, nor could poverty force him from the pursuit of his illusory objects. His faith in his ultimate success sometimes carried him on to persevere in his labours even at the cost of his life. Indeed this wonderful perseverance and sublime patience are the most striking characteristics of the alchemists. Perhaps any object less fascinating or glorious than the discovery of the philosopher's stone and the elixir of life would not have induced men to spend their time in laborious experiments. It was doubtless through the alchemical experiments that the truths were acquired that might for ages have remained unknown. The illusory nature of the object pursued by the alchemists must be borne in mind, and also the fact that the true methods of chemical science had yet to be discovered."

CHAPTER III

BURNING : THE PHLOGISTON THEORY

The Greek "Elements."

Before entering on the subject of this chapter, we must go back again to the Greek period, and make mention of some of the speculations that were put forward at that time. The philosophers of Greece had the idea that the earth and all it contained was composed of only one substance which assumed different forms and properties, thus accounting for the apparent diversity of substances. Everything was derived from this "element," as they called it, and everything could ultimately be reduced to the same "element." The philosophers, however, could not make up their minds as to what the "element" was. This, of course, was only natural, for their ideas were not founded on experiments. One said that *water* was the substance from which everything was formed, and to which everything returned ; another had the idea that everything consisted of *air* of greater or less density ; a third thought that *fire* was the beginning and end of all things ; while yet a fourth considered that *earth* was the universal principle.

Even that did not see the end of the Greek theories. Another philosopher suggested that, instead of there being only one "element," there were several. His theory was that they were four in number, namely, water, air, fire, and earth, and that everything consisted of a mixture of these "elements" in different proportions.

"Proof" of the Four-element Theory.

Now all these theories were not stated without an attempt being made to prove them. The proofs, however, were superficial, though no doubt they were accepted at the time as being quite convincing. Here is an example of the kind of proof that was given: "When green wood burned, flame showed the presence of fire, the ascending smoke proved the presence of air, the hissing and boiling gave abundant evidence of water, and the remaining ashes vouched for the last element earth." This sort of proof was regarded as ample at the time and for long afterwards.

Aristotle's Addition.

Aristotle, whose influence was felt for many centuries, amplified the four-element theory, and ascribed qualities to each of the "elements" thus:

Water was wet and cold.

Air was wet and hot.

Fire was dry and hot.

Earth was dry and cold.

The four-element theory with Aristotle's addition to it was held for about nineteen hundred years, that is, to the middle of the seventeenth century, but in the eighth century, an alchemist, Jabir ibn Hayyan, suggested the theory that all metals were composed of two principles, namely, mercury and sulphur in varying proportions. Later alchemists added a third principle, salt. It is probable that they did not mean the actual substances, mercury, sulphur, and salt, but that they considered that each substance had three parts corresponding to body, mind, and spirit in man, and that the three words represented these parts of the substance.

Van Helmont.

A Belgian alchemist, Van Helmont, completely destroyed both the Greek theory and that of the alchemists, but he reverted to one of the earlier Greek notions, and proved, as he thought, that water was the "element" from which everything was derived. One of his proofs was as follows: He took a young willow tree weighing 5 lbs., and planted it in 200 lbs. of earth. He watered it frequently, and, at the end of five years, he uprooted it, and weighed it. Its weight he found to be 169 lbs. Then he weighed the earth, and found that it had lost only 2 oz. in weight. Hence he concluded that the increase of 164 lbs. had come from the water alone—a very natural conclusion seeing that Van Helmont did not know that part of the increase had come from the air. Nevertheless, this example of the resort to experiment to support theories shows the trend of the period: the time of mere speculation was past. In every country, men were working hard in their laboratories in order to find out the facts, instead of merely drawing on their imaginations to evolve theories.

Early Observations on Burning.

From earliest times men have been impressed by the phenomena of fire, burning, and heat. Not long after the discovery of fire by primitive man, it must have come to be indispensable for cooking food, and later for the crude manufacturing processes then in use. The alchemists, too, made constant use of it in their experiments. Some of them tried to explain what actually happened when a substance burned, but their explanations were only guesses; they made no serious attempt to find out the truth. One man, however, by chance, came remarkably near making a real discovery. He happened to notice that a glowing

coal burst into flame when a blast of air impinged upon it, and that the same thing occurred when a handful of nitre was thrown on it. "Hence," he said, "nitre and air are connected, for things that are equal to the same thing are equal to one another." We now know that the kindling power of nitre and of air is due to the oxygen which they both contain. It was a fortunate occurrence, but nobody followed it up at the time, so the explanation of burning was as far away as ever.

Becher's Theory.

It was not till the middle of the seventeenth century that any real attempt was made to get at the root of the problem of combustion. A German chemist, Becher by name, thought that combustion was simply the splitting up of a substance into two or more different substances. This, of course, was the old "mercury, sulphur, salt" theory, but he gave it a new form. He said that everything that burns contains a combustible principle which he called *terra pinguis*—a fatty earth. According to Becher, when phosphorus burned, the *terra pinguis* that was in the phosphorus escaped, and the white powder that was left was the body of the phosphorus without its fatty earth. He applied his theory not only to burning in the usual sense, but also to the calcining of metals such as copper and lead. When copper was heated, it was changed into a black powder; this black powder (calx of copper), he said, was copper *minus* its fatty earth.

Stahl and Phlogiston.

One of Becher's pupils was George Ernst Stahl whose name has become famous, not because of any discovery he made, but because he introduced a theory of combustion which lasted for a hundred years or more, and which indirectly caused a great advance in chemistry. What

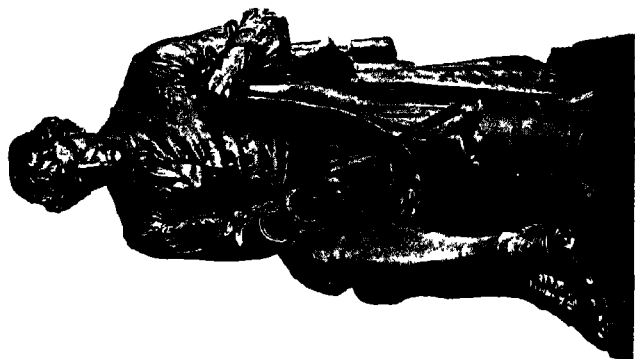


THE ALCHEMIST.

From the mezzotint by William Pether, after the painting by Joseph Wright.



PARACELSUS
From an old print



KARL WILHELM SCHEELÉ.
From the statue by Borjeson.

Stahl did was really to adopt and develop his master's views. According to Stahl, substances such as coal, wood, and oil burn because they each contain a combustible substance which he called phlogiston. Hence everything that could burn was to be regarded as a compound, one of its constituents being phlogiston, which made its escape from the substance when combustion took place. When a candle burned, the escape of the phlogiston was indicated by the flame. It was a well-known fact that if a lighted candle was placed in a confined space of air, it soon went out. This Stahl explained by saying that the air became saturated with phlogiston, and, as it could not take up any more, the candle had to stop giving it off, and therefore the flame disappeared.

Some metals when they are heated are changed into powders which were called *calces*. Stahl's explanation of this process was that the metal lost its phlogiston. Metals, therefore, according to this theory consisted of calx combined with phlogiston, and were regarded as compounds.

Stahl explained also that breathing is just another form of combustion. During that process, the phlogiston in the body was transferred to the air, and so the temperature of the body was kept up. He said that it was impossible to live in a closed space of air, because the air became saturated with phlogiston, just as it did when a candle burned in it.

“Appearances are Deceptive.”

Now, on the face of it, this theory looks very reasonable. When magnesium burns, for example, it does look as if something were escaping: the flame itself suggests it. At the end, too, a soft white powder is left in place of the original hard metallic substance, which again suggests that the magnesium has lost something. The men of those days, however, had not taken to heart the lesson contained

in the proverb, "Appearances are deceptive"—a proverb which might appropriately be hung on the walls of all scientific laboratories, and which the young scientist would do well to keep in mind. Stahl fell into the same old error as had scores of his predecessors—he made a theory without paying due regard to the facts, and without making *quantitative* experiments.

Two Objections to Phlogiston.

All the chemists who immediately followed Stahl adopted his combustion theory, and sought by it to explain the facts of chemistry that were known. As a rule, it fitted in quite well, and gave a fairly satisfactory explanation of the various changes that occurred in the course of their experiments. There were two facts, however, which they found it very difficult to account for. It had long been known that a lamp or a candle would not burn indefinitely in a closed space. As was mentioned above, Stahl said that it was because the air became saturated with phlogiston, but he brought forward no proof of his statement: it was only his idea on the matter—a possible explanation that could not be verified. It provides a good example of fitting the facts to the theory, instead of finding a theory to fit the facts, and, as will be seen later, men became so blinded by the phlogiston theory that they were unable to see the facts when they were presented to them.

The second objection was even more serious. It was a well-known fact among chemists that a metal when it was calcined increased in weight; for example, the black powder obtained by heating copper was heavier than the original copper. One would think that this fact was quite inconsistent with the phlogiston theory. If phlogiston were driven off when copper was heated, one would expect the black powder to be lighter than the original copper, not heavier as experiment showed. The supporters of

the phlogiston theory tried to explain this by saying that phlogiston had negative weight, that is, instead of having weight or heaviness, it had lightness. Thus, when the phlogiston was driven off from a metal by heat, the calx, freed from the light substance, showed its true weight. They apparently considered that a metal was like a stone attached to a cork floating on the surface of water; the stone represents the calx, the cork represents the phlogiston. If the stone and the cork are separated, the stone sinks and therefore appears to be heavier than it was before. So when the phlogiston was driven off, the calx *seemed* to be heavier than the metal. This ingenious explanation had only one defect, but it was a fatal one, namely, it could not be proved. No experimental evidence was quoted to support it.

No Rival to Phlogiston.

Despite its defects, the phlogiston theory was accepted for a long time by all the leading chemists, because no better was suggested to replace it. It was not until men learned to study the facts first and form their theories afterwards that phlogiston was dispensed with. Nevertheless, during the century or so in which it held the field, much progress was made, and the way was prepared for the revolution in chemistry that came towards the end of the eighteenth century. No outstanding discovery was made, but a **great** deal of information was collected which proved useful to later chemists in putting the subject on a surer foundation.

Jean Rey's Idea.

Jean Rey, a French doctor, investigated and discussed the calcination of metals in 1630, even before Stahl produced his famous phlogiston theory. He knew from definite experiments that tin and lead increased in weight when they were heated. He attributed the increase to

air which, he said, had been condensed by the heat, and which had attached itself to the metal. At a certain stage, he argued, the metal became saturated with air, and calcination stopped. He found an analogy in the fact that wet sand is heavier than dry sand, because small particles of water cling to the grains of sand. Rey evidently recognised that the air had something to do with calcination, and, in this respect, he was ahead of the phlogistonists.

Robert Boyle has another Idea.

Robert Boyle, whose name is well known as the discoverer of the physical law that goes by his name, also knew that the calx of a metal weighed more than the metal itself. He explained this fact by saying that particles of heat entered into the metal, and so made the calx heavier, proving, as he thought, that heat had weight. His views are indicated by the title of one of his books, *Fire and Flame weighed in a Balance*. Curiously enough, other chemists adopted the same view until one man performed the simple and obvious experiment of weighing a body when it was cold, and again when it was hot. He found no change in weight, showing that heat had no weight, and that therefore the calx of a metal could not be simply metal *plus* heat.

Robert Hooke nearly makes a Discovery.

A man who nearly arrived at the modern explanation of combustion was Robert Hooke, who lived at the same time as Boyle and assisted him in his experiments. He noticed in 1674 that, in some respects, nitre and air were very similar. It was mentioned above that one of the alchemists discovered that a glowing piece of coal could be kindled into flame either by a current of air, or by some nitre. Hooke rediscovered this forgotten fact, and came to the same conclusion as the alchemist had come to,

BURNING: THE PHLOGISTON THEORY 21

namely, that there was something common to air and nitre—something that assists combustion. He went further and said that some constituent of the air was fixed in the nitre, and that it was this constituent that took an active part in burning.

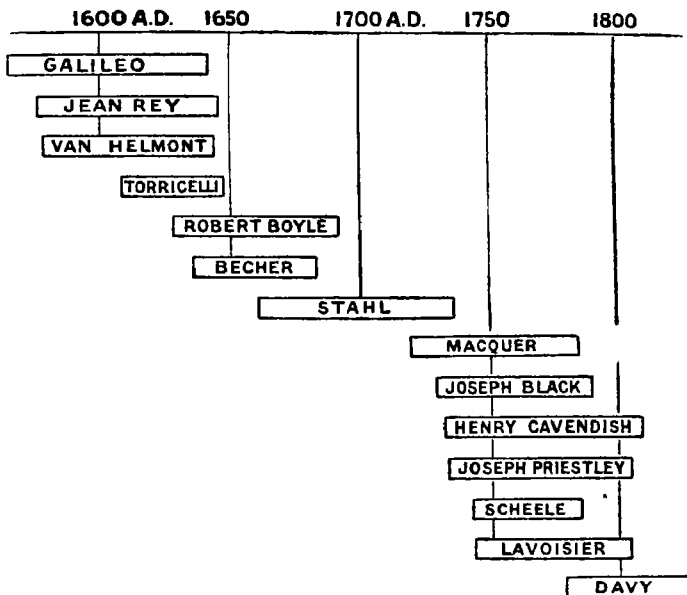


FIG. 3.—Chart showing lives of some of the outstanding scientists of the seventeenth and eighteenth centuries.

John Mayow agrees with Hooke.

About ten years later, another English chemist, John Mayow, arrived at practically the same conclusion as Hooke. He said that fire was supported, not by the air as a whole, but by the more active and subtle part of it. He called this part of the air *nitrous-air*, because it was present in nitre.

The two last-mentioned men, it will be seen, came very near to the modern explanation of combustion, but probably it was "more by luck than good guidance." Anyhow they failed to convince others and bring them to their views, with the result that their work was almost forgotten. About a century later, it was found that they had been on the right lines, and if only they had pursued the matter further, they would have anticipated later discoveries.

A Century Later.

It was almost exactly a hundred years after Mayow arrived at his conclusions, before any further experiments of any consequence were performed in connection with burning. The interval, however, was not barren, for with fresh minds applying themselves to chemistry, new methods of experiment were introduced which were a great improvement on the earlier methods. It will be seen from the following account how great that improvement was. Lavoisier, of whom more will be said in later chapters, calcined lead and tin in a bell-jar inverted over water contained in a basin. By this means he was able to see if any change took place in the volume of the air. He knew the weight of metal, and the weight of air, and at the end of the experiment he weighed the calx and the remaining air. He found that the weight of air that had disappeared was equal to the weight by which the metal had increased. He therefore concluded that a part of the air had combined with the metal during calcination. This and similar experiments performed by Lavoisier led ultimately, as we shall see, to the modern solution of the whole problem of burning.

The various theories that were put forward in an attempt to explain the phenomenon of combustion were one by one discarded in the light of subsequent knowledge. During the time that each was thought to be correct, it explained

the facts that were then known, but when new facts emerged which contradicted the theory, it had to be dropped and another adopted. Even in the present scientific age, all knowledge is held on the understanding that it may have to be modified at any time ; in fact, during recent years, several important discoveries have been made which have altered our ideas about certain things in a most wonderful manner.

CHAPTER IV

BURNING AND RUSTING

BEFORE pursuing further the development of chemistry historically, we shall at this stage discuss one or two of the experiments usually performed in the laboratory.

Rusting of Iron—early Theories.

Iron has been known from prehistoric times, and one of man's earliest observations would be that it rusted when left exposed. No doubt he would speculate as to the cause of its rusting, and he would in all probability ascribe it to some supernatural agency. In the fourth century B.C., Plato, one of the Greek philosophers, stated that, when iron rusted, it lost something, though what that "something" was, he did not say. Judging by appearances, one would say that Plato was right; it certainly does look as if iron when it rusts is gradually eaten away. The alchemists, though they made extensive use of iron as a metal, did not investigate the nature of the change which turns iron into a brown powder: they were too busy trying to make gold to pay much attention to a base metal like iron. Some of the chemists of the seventeenth century, including Robert Boyle, turned their attention to the rusting of iron, and concluded that it was caused by "corrosive effluvia in the air," but very carefully abstained from giving details. The statement contains the same idea as Plato expressed; Plato said the iron was corroded or eaten away; Boyle and others said that something in the

air caused the iron to corrode. Lastly, according to the phlogiston theory, iron, when it rusted, simply lost its phlogiston.

In all these theories about the rusting of iron, no mention has been made of any experimental evidence having been brought forward to support them. For the most part, the explanations given were no explanations at all, being the result of mere speculation. In the cases where experiments were performed, they were crude and unconvincing because they were not *quantitative* experiments. We can learn a great deal from the history of chemistry, and one of the lessons it teaches us is that, by beginning with quantitative experiments, we can avoid many of the errors into which the early investigators fell. Hence it is that the first question we ask when we begin the study of the rusting of iron is "Is there a change in weight when iron rusts?"

Change in Weight when Iron rusts.

If some iron filings are weighed, moistened with water, allowed to rust, and the *dry* rust weighed, it will be found that there is an increase in weight. This one fact at once disposes of all the theories which state that the iron loses something. Now where has this increase come from? There were only three things in contact with the iron, namely, air, water, and the containing vessel. The last may be weighed before and after the experiment, and its weight will be found to be unaltered. There remain, therefore, only air and water. The increase must have come either from the air, or from the water, or it may be that it has come partly from both.

Does the Increase come from the Air?

To find out if any of the increase comes from the air, some moist iron filings may be placed in a glass jar which

is then inverted with its mouth under the surface of water. By this means, a certain volume of air is cut off from the atmosphere, and any change in volume may be seen by the rise or fall of the water in the jar. If the apparatus is now set aside, and examined next day, it will be found that some water has risen in the jar, showing that some air has been used up. This proves that part at least of the increase in weight has come from the air; the iron has combined with the air or with something in the air. If the height to which the water has risen is measured, and

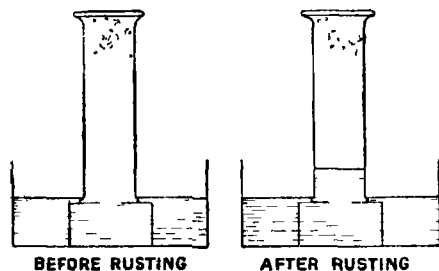


FIG. 4.—Before and after rusting.

the apparatus allowed to stand till the following day, it will be found on examination that the water has risen still farther. If these daily observations are continued, there will come a time when measurement will show that the water has stopped rising. There are two possible explanations of this: either all the iron has rusted, or the iron has combined with only one constituent of the air which has now been all used up.

Has all the Iron rusted?

It is an easy matter to find out which of these alternatives is correct. All that has to be done is to remove the remaining gas and introduce fresh air into

the jar, set it aside as before, and examine it after a few days. Provided a sufficient quantity of iron filings is used, the water again rises, and more, it rises to exactly the same level as before. This shows that the iron continued to rust when fresh air was introduced, and that lack of unrusted iron was not the reason why rusting stopped. The fact that the water rises to the same level as before suggests that the iron has combined with a certain constituent in the air, and, when this is all used up, rusting stops. If, in either of the last two experiments, the volume of water that rose in the jar, and also the capacity of the jar are measured and compared, the volume of the water will be found to be one-fifth of the capacity of the jar. Thus one-fifth part of the air by volume has united with the iron. If a lighted taper is plunged into the remaining four-fifths, the light is immediately extinguished, showing that what is left is not ordinary air, for if it were, the taper would continue to burn.

These experiments show (1) that iron when it rusts combines with something in the air which constitutes one-fifth part of the latter by volume; (2) that the air consists of at least two parts with different properties, one which is necessary for the rusting of iron and for the burning of a taper, the other which takes no part in these changes.

Water necessary for Rusting.

It is a matter of common experience that rusting takes place in the presence of moisture. It may be shown that air alone will not cause rusting by allowing a bright iron nail to stand in perfectly dry air. The nail will remain bright for an indefinite time under these conditions. Thus water as well as air is necessary for the rusting of iron, and it can be shown that the increase in weight after rusting comes partly from the air and partly from water.

Prevention of Rusting.

The rusting of iron is familiar to everyone, as are also some of the means employed to prevent it. If iron is to be preserved, it must be protected from contact with air and water. This is done by covering it with a layer of a substance that is not affected by moisture or by air. Such substances are paint, enamel, nickel, zinc, and tin. A so-called tin can is really an iron can coated with a thin layer of tin.

Rusting of Mercury.

It is not such a well-known fact that mercury will rust under certain conditions. Mercury is often used in the course of experiments in the laboratory, but its appearance is always bright and silvery with no suggestion of tarnishing due to rust. The reason for this is, that mercury does not rust at the ordinary temperature ; it has to be heated nearly to its boiling-point, which is 357° C., and kept at that temperature for some time before any change in its appearance is noticed. If mercury is kept at a temperature of about 350° C. for several days, a scum, almost black, gradually forms on the surface, and, if allowed to cool, turns brick red. This red powder is mercury rust.

Early Theories.

Mercury was discovered before 300 B.C., and it was then called "liquid silver," which certainly describes its appearance. Later, it came to be known as "quicksilver" (quick=living¹). The alchemists used it frequently as an ingredient in their various preparations during the search for the philosopher's stone, and discovered the fact that it rusted at a certain temperature. Their explanation of this process was that the humidity (wetness) of the mercury

¹ Compare the Biblical phrase, "the quick and the dead," meaning "the living and the dead."

escaped, and so left a dry powder, which, of course, did not explain it at all. As the theories of the alchemists changed, their explanations of different processes changed also, and we find it stated later that, when mercury rusted, the spirit of the mercury was set free and the body left as a powder. When the phlogiston theory was proposed, the explanation was that the mercury lost its phlogiston.

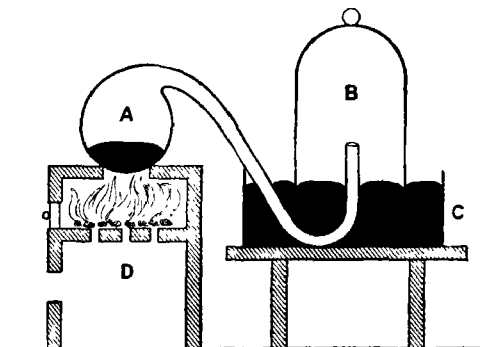


FIG. 5.—Lavoisier's Experiment with Mercury. A. Retort containing Mercury; B. Jar containing Air; C. Basin with Mercury; D. Charcoal Furnace.

Lavoisier's Experiment.

The classic experiment in this connection was performed in the eighteenth century by the famous French chemist, Lavoisier, whose name was mentioned in the previous chapter. He placed some mercury in a retort, the end of which led into a jar inverted over mercury contained in a basin. He heated the mercury in the retort for twelve days continuously, keeping it at a temperature just below its boiling-point. On the second day, he saw small black specks on the surface of the mercury in the retort. The next day more of these specks appeared, and during the next four or five days the number gradually increased.

After that, however, he observed no further change although the heating was continued for twelve days in all. During the time that the specks were appearing in the retort, mercury simultaneously rose in the jar, and when the formation of specks stopped, the mercury stopped rising in the jar. Lavoisier deduced from this that some of the air had been used up by the mercury in rusting. On measuring the volume of this part of the air that had been absorbed, he found it to be about one-fifth of the original volume of air in the apparatus. He noticed also that the "air" that remained did not support combustion.

Burning of Phosphorus.

The element phosphorus was quite unknown before the seventeenth century. It was discovered by Brandt of Hamburg in 1669. The word phosphorus means "light-bearer"; the name was given to it because it was found to give out light in the dark. Phosphorus, when exposed to the air, gives off fumes, in fact, it burns spontaneously. Hence it must be kept under water. It must not be touched with the fingers unless it is under water, otherwise a severe burn may result.

The greatest commercial use of phosphorus is in the making of matches. Phosphorus matches appeared for the first time in the middle of the nineteenth century, and in spite of the fact that phosphorus is poisonous, and the workers in match factories suffered from a peculiar disease, called "phossy jaw," they gained a great amount of popular favour. Nowadays ordinary matches are tipped with a compound of phosphorus and sulphur which has not these objections. Safety matches contain no phosphorus at all, but the strip of brown paper on the box on which the matches must be struck is coated with a preparation containing phosphorus.

For one hundred years it was thought that phosphorus

was a compound of phlogiston and some other substance, but Lavoisier proved that, when it burned, it did not lose phlogiston or anything else, for it increased in weight. He then did with phosphorus what he had done with mercury, namely, burned it in a closed space of air, and showed that it increased in weight just as much as the air decreased in weight.

Conclusions to be drawn.

These experiments, and many more similar to them, show that when a substance burns, or when a metal rusts in air, it takes something from the air, and all the experiments point to the fact that always the same "something" is taken, because, in each case, one-fifth part of the air by volume is used up, and four-fifths left behind. The remaining four-fifths does not support combustion nor can life be maintained in it. Thus it is seen that air consists of at least two parts—one that takes part in combustion and respiration, the other that takes no part in these processes. Our next task is to isolate this gas that constitutes one-fifth part of the air, and to study its properties.

CHAPTER V

THE DISCOVERY OF OXYGEN

Joseph Priestley.

Joseph Priestley was born near Leeds in 1733. He was of humble parentage, his father being a weaver and dresser of cloth, carrying on his occupation at home, as was the custom in those days. When Joseph was seven years of age his mother died, and he was entrusted to the care of his aunt. He was sent to school, and, besides learning Latin and Greek, he spent his holidays learning Hebrew under the tuition of a minister ; this when he was between twelve and thirteen years of age. When he was sixteen he contracted a severe illness, the effects of which he felt for several years afterwards. About this time he learned French, Italian, and German without the help of a teacher.

He was educated for the Christian ministry, but his illness temporarily caused him to abandon the idea. When he had sufficiently recovered, however, he resumed his theological studies. He had an impediment in his speech, and, at times, he thought that defect would prevent his entering the ministry ; but he persevered, and, though he was never a fluent speaker, he seems to have improved in this respect as time went on.

Eventually he began preaching, but he was not particularly successful, because he had developed views which were contrary to the orthodox teachings of the Church. He opened schools in several places in which he ministered, partly because his salary as a minister was so small ; it

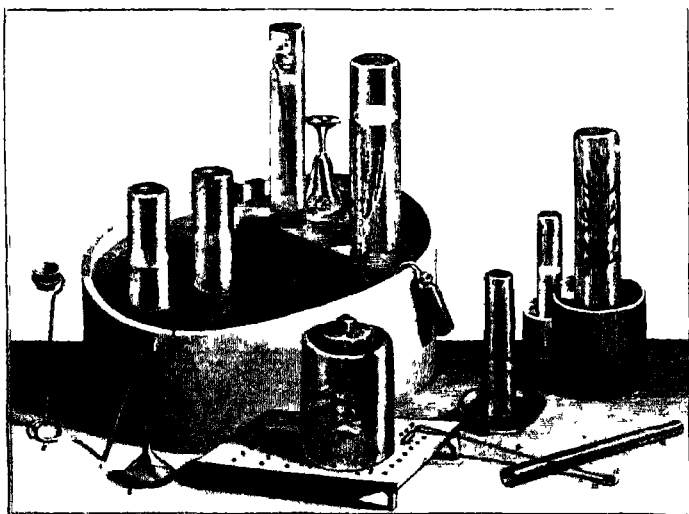


From the engraving by F. Levasseur, after the painting by L. David.



JOSEPH PRIESTLEY, F.R.S., F.R.S.

From an old print



PRIESTLEY'S PNEUMATIC TROUGH, AND OTHER APPARATUS

From a contemporary engraving

was only £40 a year in one place. Of one of those schools he writes : " There I was employed from seven in the morning till four in the afternoon without any interval except one hour for dinner, and I never gave a holiday on any consideration, the red-letter days, as they are called, excepted." One can imagine that Priestley's school would not be a popular one with his pupils.

How he was attracted to Science.

Priestley wrote several books and pamphlets on theological subjects, in fact he never altogether abandoned the studies with which he began life. He was attracted to science, however, through meeting Dr. Franklin who had already become famous because of his researches in electricity. As a result of this friendship, Priestley wrote a *History of Electricity* which was his first scientific work. After this, he began to devote more time to science, and especially to chemistry. His experiments on gases led him to invent the now well-known pneumatic trough, a very simple piece of apparatus, but one without which we should be very much at a loss when experimenting with gases. A crude form of the trough had been used by a former chemist, Stephen Hales, but Priestley gave it its modern form.

His Characteristics.

Priestley's experiments were conducted in rather a slipshod manner. We are told, for example, that the water in his pneumatic trough was sometimes not changed for weeks at a time. Naturally this complicated his results in some cases. His general method of working, too, was very casual ; he did not plan out a definite series of experiments with the idea of investigating some particular problem, but just did any experiment that his fancy dictated. This, however, does not detract from Priestley's

work, for many other experimenters were performing the same experiments as Priestley performed without making any new discovery. Priestley, on the other hand, added considerably to the stock of scientific knowledge, because he had the gift of being able to grasp the meaning of his experiments in relation to the knowledge of the time.

Discovery of Oxygen.

Priestley's name is now world-famous, principally on account of his great discovery of oxygen in 1774. Here is his own account of it, with explanatory notes in brackets : " Having procured a lens [burning glass], I proceeded with great alacrity to examine, by the help of it, what kind of air [gas] a great variety of substances would yield, putting them into vessels filled with quicksilver, and kept inverted in a basin of the same. After a variety of other experiments, I endeavoured to extract air [gas] from *mercurius calcinatus per se* [mercury rust], and I presently found that, by means of this lens, air [gas] was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not imbibed by it [the gas did not dissolve]. But what surprised me more than I can well express, was that a candle burned in this air with a remarkably vigorous flame. I was utterly at a loss to account for it." Besides burning a candle in this new gas, he placed a mouse in a vessel filled with it, and found that it lived twice as long as it would in ordinary air. He inhaled the gas himself, and he said that his " breast felt peculiarly light and easy for some time afterwards."

One can easily imagine Priestley with his new burning glass, which was a useful instrument for heating substances, before coal-gas was introduced for heating, going round his laboratory and testing the action of heat on different substances. In some cases, he would get no result, in

others a result already known, but in the case of mercury rust, he obtained an entirely new gas whose properties caused him to express surprise and delight. He tried to explain what had happened, and came to the conclusion that this gas was simply ordinary air greatly purified. His explanation of the process of changing mercury to rust, and back to mercury again was something like this : when mercury is heated, it loses its phlogiston which passes into the air ; when mercury rust is heated, phlogiston passes from the air into the rust, and thus produces mercury again ; the " air " which is given off has lost its phlogiston, and he therefore called it " dephlogisticated air." It was not till several years later that it received its modern name, oxygen, as we shall see in the next chapter.

Later Work.

Priestley continued his chemical experiments for many years, and did much useful work in connection with various substances which does not need to be recorded here ; but he explained all his results in terms of the phlogiston theory to which he adhered to the end of his life. We must remember that chemistry was only a hobby with him ; he was a minister first, and a scientist second, but he contributed more to the progress of science in his leisure time than many before and since have done by making science their main business in life. As small points of interest, it might be mentioned that, in one of Priestley's books, reference is made for the first time to the use of indiarubber as an eraser, and that he was the inventor of soda-water.

The end of Priestley's career, though not untimely, was not a glorious one. At the time of the French Revolution, he was living in Birmingham. He was accused of sympathising with the Revolutionaries, and his church and house containing his apparatus and his library were burned

to the ground by an infuriated mob. He himself just managed to escape with his life to London by the help of his friends. Shortly afterwards he emigrated to America where he died ten years later at the age of seventy-one.

Karl Wilhelm Scheele.

The honour of the discovery of oxygen is shared by Priestley and Karl Wilhelm Scheele, who was born in Sweden in 1742. In his youth, Scheele was apprenticed to an apothecary in Gothenburg for eight years, and, during that period, he read all the books on chemistry that he could obtain, and, at the same time, performed as many experiments as he could with the limited amount of apparatus at his disposal. Later, he went to Upsala, where most of his important work was carried out.

Although Scheele died when he was only forty-three years of age, no one person has ever made as many important discoveries as he did. The only one of his discoveries with which we are concerned at present is his discovery of oxygen which he made quite independently of Priestley, of whose work in this connection he was entirely ignorant. He did not publish his discovery till after Priestley had announced his, but it was made in the year 1771. As a matter of fact Scheele perhaps deserves more credit than Priestley for this particular discovery, for the former arrived at the result he did, not by chance, but at the end of a carefully planned series of experiments. Priestley's experiments very often had no particular object in view, whereas Scheele's were always directed towards some definite goal. This is one reason for the remarkable success he attained.

How he discovered Oxygen.

Scheele tackled the problem of combustion and rusting. He was a firm believer in phlogiston, and argued, in common

with others, that, if certain substances which were supposed to contain phlogiston were placed in a confined space of air, they would, in burning or rusting, give up their phlogiston to the air, and thus the phlogiston could be collected and examined. One of the experiments he did was the usual school experiment of allowing iron filings to rust in a confined volume of air, the air being contained in a jar inverted over water. He noticed, however, that the air decreased in volume, and that the gas left was incapable of supporting combustion, so that, instead of something being added to the air, something was taken away from it. He concluded,

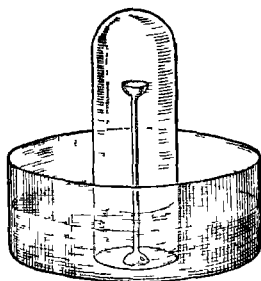


FIG 6 —The Rusting of Iron. Scheele's Apparatus

after doing sixteen different experiments using different substances, that air consists of two parts: one which supports combustion, and another which does not. The former he called *fire-air*. Later, he obtained *fire-air* from several different substances, among which were nitre and mercury rust. Needless to say, Scheele's *fire-air* was the same gas as Priestley's *dephlogisticated air*, the gas which we now call oxygen.

It is very doubtful if either Priestley or Scheele realised the importance of his own discovery, but that is not to be wondered at, considering the existing state of knowledge. Their chief function was that of bringing the facts to light ;

others were left to interpret them. With the discovery of oxygen, the problem of combustion was nearly solved, but neither of these two men solved it, probably because they did not realise that it was a problem, the phlogiston theory in their opinion being quite an adequate explanation. Nevertheless, the work of Priestley and Scheele, and others yet to be mentioned, was destined, in the hands of others, to lay the foundations of modern chemistry.

CHAPTER VI

LAVOISIER

Progress in Physics.

The seventeenth century is an important century in the history of physics. The labours of Torricelli in Italy, Guericke in Germany, Pascal in France, and Boyle and Newton in England resulted in a tremendous advance on previous work, and the invention of the barometer, the telescope, the air-pump, and the thermometer paved the way for other and more far-reaching discoveries.

Chemistry's Wonderful Century.

Chemistry had a turning-point which is even more definite than in the case of physics, but it is located in the eighteenth century. The following five pre-eminent chemists lived in this century, and, for a period of forty-three years, they were contemporaries :

Joseph Black	.	.	.	1728-1799
Henry Cavendish	.	.	.	1731-1810
Joseph Priestley	.	.	.	1733-1804
Karl Wilhelm Scheele	.	.	.	1742-1786
Antoine Laurent Lavoisier	.	.	.	1743-1794

Black's name is well known for his study of latent and specific heats, and his work in chemistry will be described in Chapter XI. The work of Priestley and Scheele was spoken of in the previous chapter. Cavendish's discoveries

will be mentioned in Chapter X. These four men form a distinguished group of chemists whose discoveries were of the greatest importance to the future of science, but they were all alike hampered by the phlogiston theory which so blurred their vision that they did not realise the importance of their own discoveries. Lavoisier, on the other hand, the fifth of the great chemists of this century, was not wedded to any theory. While the above four chemists tried to fit the facts into the phlogiston theory, Lavoisier examined the facts first, and made a theory to fit them, thus showing the true scientific spirit.

Lavoisier.

Lavoisier was born in Paris. He received an excellent education, and, though it was intended that he should enter the legal profession, he early turned his thoughts to science, and gained a sound knowledge of it. At the age of twenty-one, he gained a gold medal awarded by the French Government for the best method of lighting the streets of a large city. In this early work, we are told, Lavoisier showed the same patient care and absolute accuracy as characterised his work all through life. At first, he did not devote all his energies to chemistry, but the work of Priestley, Scheele, and others attracted him, and he afterwards adopted chemistry as his life-work. He was evidently a business man as well as a scientist, for he succeeded in making such a large sum of money that he was regarded as an aristocrat, which in the end proved his undoing.

His Services to France.

Lavoisier rendered service to the State on several occasions. At that time the gunpowder used by the French army was of very poor quality. Lavoisier made investigations which resulted in such an improvement in

the gunpowder turned out by the factories that it was for a time the best in the world. He acted as secretary and treasurer of the Commission set up by the Revolutionaries at the time of the French Revolution to change the system of weights and measures, and played a large part in evolving the Metric System which this Commission produced.

His untimely Death.

When the Revolution finally succeeded, Lavoisier was imprisoned because he was a farmer-general of the revenue, that is, he was one of a company of financiers who had been permitted by the government to levy taxes on the country. His friends made strong appeals on his behalf on the ground of his learning and scientific services, but they were met with the remark: "The Republic has no need of learned men." He was guillotined in 1794. A later scientist has said that the head of Lavoisier fell in a moment, but a hundred years had not sufficed to produce such another.

His Experiments on Combustion.

Among Lavoisier's first chemical experiments was a series on combustion. He was thus pursuing a subject which had occupied the minds of chemists for several centuries, but Lavoisier was one of the first to recognise that the balance should be the first resort in all chemical investigations. Others had used the balance, but they did not attach as much importance to it as Lavoisier did. Joseph Black was an exception, but his original work was not extensive enough for his influence to be properly felt. It was known before Lavoisier's time that the products of combustion and calcination weighed more than the original substance, but Lavoisier went farther than this, and proved by experiment that the increase in weight

was equal to the decrease in weight of the air in which the burning took place, thus proving conclusively that something was taken from the air. His experiment with mercury was described in Chapter IV., whereby he showed that mercury when it rusted caused the volume of the air enclosed in the apparatus to diminish by one-fifth part. He performed a similar experiment, with tin this time, weighing the tin and the enclosed air before heating. When the calcination stopped, he weighed the remaining air and the



FIG. 7.—Lavoisier in his Laboratory. (From an old print.)

calx, and found that what the tin had gained in weight the air had lost. He next tried to regain the part of the air that had combined with the various metals he had calcined, but failed to select those that would have given him the desired result. He required this lost air before he could make any further progress.

Lavoisier meets Priestley.

In the year 1774, Priestley, who at that time was in the service of Lord Shelburne as his librarian and companion, and who was travelling with his patron in Europe, stayed for some time in Paris. While there, he met many

eminent men, among whom was Lavoisier. Priestley, in the course of conversation with the French chemist, mentioned that he had obtained a very peculiar gas by heating mercury rust. Lavoisier lost no time in repeating the experiment, and he at once realised that it supplied the key to the whole situation: this was the lost air that he had tried to obtain. He soon came to the conclusion that this gas, Priestley's *dephlogisticated air*, Scheele's *fire-air*, must be present in the air, and make up one-fifth part of it by volume. He saw that mercury when it rusted combined with this gas, and that when the mercury rust was heated it gave up the gas again. He afterwards named the gas *oxygen*. The remaining gas in the air which we now call nitrogen, he called *azote* (without life), and this name is used in France to this day.

The New Theory of Combustion.

Lavoisier now devoted twelve years to the complete study of all the facts in connection with combustion. He repeated his own experiments and those of others with a care and accuracy that had never before been bestowed on any experiments. He had constant recourse to the balance, and the conclusiveness of his proofs was mainly due to that fact. The result of all his labours was the bold declaration that phlogiston was a myth, and that therefore the theory of which it was the basis was absolutely unsound. In its place, he put forward the theory that, in combustion and rusting, oxygen combined with the burning or rusting substance. Mercury rust, he explained, was a compound of mercury and oxygen, and not mercury deprived of its phlogiston as had hitherto been supposed. Phosphorus when it burned, did not lose phlogiston or anything else, but combined with the oxygen of the air. Lavoisier's theory was based, not on mere speculation, but on solid fact. He did not require to invent any mysterious sub-

stance with unusual properties ; Priestley's discovery of oxygen gave him all he needed.

Lavoisier's views were opposed by many eminent men. Even Priestley, whose discovery was responsible for the new theory, adhered to the phlogiston theory till his death thirty years after his discovery was made. He and others could not bring themselves to abandon the theory on which all their work had been based. Gradually, however, it was seen that there was not an argument left in favour of the phlogiston theory which could not, with greater force, be applied to the oxygen theory, and all reasonable chemists came ultimately to agree with Lavoisier, whose views on combustion have never since been questioned.

The Indestructibility of Matter.

Another of Lavoisier's contributions to science which may be mentioned here is his statement of the principle of the indestructibility of matter. He showed that matter could be changed, but it could neither be created nor destroyed. To illustrate by a simple experiment: if some moist iron filings are placed in a bottle which is then tightly stoppered, and laid aside for several days, the total weight at the end of that time will be the same as it was at the beginning. The iron rust will be heavier than the original iron filings, but, on the other hand, the "air" will weigh less than the original air, the total weight being unchanged. Matter cannot be annihilated. When anything is "destroyed," it is merely changed into another form. This is one of the fundamental principles of chemistry. If, during an experiment, something entirely disappeared, or something else suddenly appeared, the experiment would be worthless ; we should never know what was going to happen, and could not depend on always getting the same result from the same experiment

"The Father of Modern Chemistry."

One remarkable fact about Lavoisier which has not yet been alluded to is that he did not discover a single new substance. What he did was to interpret his own work and that of others. He brought together apparently isolated facts and showed their relation to one another. For example, Priestley confessed that he was utterly at a loss to account for the presence of the gas he obtained by heating mercury rust, or mercuric oxide, as we should call it now. Lavoisier at once perceived that this gas must have come originally from the air during the rusting of the mercury. Lavoisier's work covered a much wider field than has been indicated in this chapter. It is generally admitted that he was the greatest chemist of his time, and that none comparable to him had appeared before his time. He was a natural genius whose services to chemistry can hardly be overestimated. He has been deservedly called the "Father of Modern Chemistry" for, with the overthrow of the phlogiston theory and the acceptance of Lavoisier's oxygen theory of combustion, a new era in chemistry was ushered in.

CHAPTER VII

THE AIR AND ITS CONSTITUENTS—

(I) AIR A MIXTURE

Air one of the Greek "Elements."

It will be remembered that air was one of the four "elements" of which the ancient Greek philosophers supposed that everything consisted, and that, though Van Helmont, at the beginning of the seventeenth century, rejected this theory, it persisted for some time afterwards. As a matter of fact, the alchemists do not seem to have attached much importance to it; the attitude they appear to have taken up was: Aristotle said so, therefore, it must be right. This blind confidence in Aristotle hindered the progress of science for centuries, for it was not only in this matter of the elements, but in others besides, that his conclusions were accepted without any attempt being made to verify them by experiment.

Van Helmont's Views on Gases.

Van Helmont appears to have considered air to be a simple substance, though he did not agree with the Greeks that it was one of the substances of which everything was composed. In the course of his experiments, he encountered other gases with properties different from those of air, in fact, he was the first to make a study of gases in general, but he thought they were all simply air containing impurities which accounted for their different properties. It is of interest to note in passing that it was Van Helmont who first used the word *gas*, which he got from *gahst* or *geist*, meaning a spirit. Before his time, and even long

after it, all gases were called *airs*. In the following century, Priestley spoke of *dephlogisticated air*, and Scheele of *fire-air*, when referring to the new gas.

Boyle's Idea of an Element.

Robert Boyle made a much more serious attempt than Van Helmont to upset the four-element theory. He put forward the view that elements were certain simple bodies which make up more complex bodies, and into which those complex bodies may be split up. This idea contained the germ of the modern definition of an element, but Boyle was rather vague about it; in fact, he was not sure if such elements really existed. In justice to Boyle, we must remember that he lived in an age when the search for the philosopher's stone was still being pursued, and that therefore he had not the facts at his command with which to form theories. As it was, he brought an acute mind to the study of chemistry, and science benefited greatly from his critical investigations.

Lavoisier's Definition of an Element.

It was Lavoisier who first had clear and definite ideas on the subject. He defined an element thus: "An element is a substance from which no simpler body has as yet been obtained; a body in which no change causes a diminution of weight. Every substance is to be regarded as an element until it is proved to be otherwise." Here was a very simple definition, and it is the one that is still adopted. To put it in a slightly different form, an element is a substance which has not yet been decomposed, that is, split up into other substances. For example, mercury is an element, because, by no known process, can it be decomposed into other substances. In Lavoisier's time, many substances were classed as elements which, as new methods were devised, subsequently proved to be decomposable, and the same may be true to-day. About ninety

different substances are now called elements, but it is possible, and, in view of recent chemical researches, highly probable, that some of them are not elements.

Air not an Element.

It is clear from the definition of an element, and from the experiments of Lavoisier and others that air is not an element in the modern sense of the term, because it can be split up into at least two gases, one that is used up during combustion, and one that takes no part in burning. As a matter of fact, more than two gases are present in air, as we shall see presently. It is difficult to say when the discovery was made that air is not an element. Many experimenters had glimpses of the truth, but either they did not draw the correct conclusion from their experiments, or they did not pursue the subject far enough. Among the first to have clear ideas on the subject was Scheele. The series of experiments he performed which led to the discovery of oxygen proved that air consisted of two parts, and that therefore it was not elementary.

Proofs that Air is a Mixture.

If air is not an element, it may be either a mixture or a compound. That it is the former may be shown in several ways. (1) There is a law in chemistry, based on the results of thousands of experiments, which states that any chemical compound always consists of the same elements in the same proportion by weight; in other words, the composition of a chemical compound is always the same. If samples of air, taken from different places, are tested, it is found that their composition is not exactly the same. The difference may be very small, but even a small variation in composition is sufficient to exclude a substance from the class called compounds. (2) Whenever a chemical change takes place, there is almost always either an absorption or an evolution of heat. Now no

such effect is observed when oxygen and nitrogen are mixed, hence we may conclude that no chemical action takes place, that is, the gases have mixed, and not combined. (3) Air can be liquefied by the application of pressure to it accompanied by a lowering of its temperature. It is then a pale blue liquid, and it is found that this liquid has not a definite boiling-point at atmospheric pressure. It begins to boil at $-195^{\circ}\text{C}.$, and, during boiling, the temperature gradually rises to $-182^{\circ}\text{C}.$ If liquid air is distilled, the first part of the distillate is almost pure nitrogen, while the last part is almost pure oxygen. If liquid air were a compound, it would have a fixed and definite boiling-point, and distillation would not separate it into its constituents. Hence air must be a mixture. (4) The properties of air are the average of the properties of its constituents. For example, the density of air can be found if the densities of its constituents are known, thus:

1 litre of oxygen weighs 1.44 gm.

1 litre of nitrogen weighs 1.26 gm.

1 litre of air = $\frac{1}{5}$ litre of oxygen + $\frac{4}{5}$ litre of nitrogen.

($\frac{1}{5}$ litre of oxygen + $\frac{4}{5}$ litre of nitrogen) weighs ($\frac{1}{5} \times 1.44 + \frac{4}{5} \times 1.26$) gm.

or $(0.288 + 1.008)$ gm.

or 1.296 gm.,

and this is the weight of a litre of air as found by experiment. If air were a compound, its density would not bear this simple relation to the densities of oxygen and nitrogen.

(5) When air is shaken up with pure water, it does not dissolve as a single substance as a compound would do. Oxygen is about twice as soluble in water as nitrogen, and the proportions of the gases in solution is not 1:4 as in the air, but about 1:2.

Each of these facts by itself is sufficient proof that air is a mixture of gases, and not a compound, and, taken together, they put the question beyond all possible dispute.

CHAPTER VIII

THE AIR AND ITS CONSTITUENTS— (2) OXYGEN

Occurrence.

Oxygen is the most widely distributed of all the elements. It occurs free in the air, constituting 20.99 per cent. of it by volume, and in combination with other elements in all parts of the earth. It enters either directly or indirectly into nearly every operation natural or artificial that goes on around us. None of the ordinary processes of combustion could take place in the absence of oxygen, nor as we are at present constituted could we continue to live were all the oxygen taken out of the air.

Preparation.

The discovery of oxygen by Priestley and Scheele was recorded in Chapter V., and the new theory of combustion evolved by Lavoisier, in which oxygen plays the most important part, was described in Chapter VI. The gas may be prepared by several methods, for example, by heating mercuric oxide, the method by which Priestley discovered it. This process, however, requires a very high temperature, and besides, the percentage of oxygen in mercuric oxide is only 7.4; for these reasons, this method is never used if a large quantity of oxygen is to be prepared. A convenient laboratory method is to heat potassium chlorate which contains 39.2 per cent. of oxygen, all of which may be driven off by heat. It has been found that by mixing the potassium chlorate with a substance called

manganese dioxide, the oxygen is driven off more quickly, and at a lower temperature than with potassium chlorate alone. The part played by the manganese dioxide in this reaction is not easily explained, for, although it helps the potassium chlorate to give up its oxygen, it is found to be unchanged when the action has stopped; exactly the same weight of it is left as was present at the beginning. Although, as its name indicates, manganese dioxide contains oxygen, the gas is not driven off from it by heat unless it is heated to a very high temperature; all the oxygen collected comes from the potassium chlorate, and, at the end, potassium chloride and manganese dioxide are left. A substance such as manganese dioxide which increases or decreases the rate of a chemical action without itself having undergone any chemical change at the end of the action is called a *catalyst*.

Commercial preparation of Oxygen.

While the laboratory method of preparing oxygen is quite satisfactory for producing the small quantities required for experimental purposes, the world's requirements of oxygen could never be met in this way; a more economical process is necessary. Brin's process was devised in 1886 for the production of oxygen on a large scale. About thirty-five years previously, it had been discovered that a substance called baryta, if heated in air to about 540° C., combined with oxygen, and that, if this new substance, barium peroxide, was heated to about 870° C., the oxygen was driven off again. This, it will be noticed, is very similar to what happens when mercury is heated, and the mercuric oxide decomposed by heating more strongly. It is costly, however, to produce frequent changes of temperature, so this discovery did not seem to be of much importance, till it was found that the same result could be obtained by changing the pressure instead

of the temperature. The process is as follows : Baryta in lumps is placed in iron retorts which are heated in a furnace. Air is pumped through them under pressure for a few minutes. The baryta combines with the oxygen of the air to form barium peroxide. The air in the retort which has now lost some of its oxygen is removed, and, when the pressure is considerably reduced, the barium peroxide gives off oxygen. The oxygen is led away and compressed in steel cylinders. The baryta can be used over and over again.

In recent years this process has been superseded by another, the fractional distillation of liquid air. This process was referred to in Chapter VII. in another connection. When liquid air boils, it is possible to regulate the pressure and temperature so that the nitrogen, which has the higher boiling-point, evaporates first, leaving almost pure oxygen. The oxygen is then allowed to evaporate, and is pumped into cylinders. Most of the oxygen used for industrial purposes is now prepared in this way.

Properties.

Oxygen is a colourless, odourless, and tasteless gas. It is slightly heavier than air, one litre of it weighing 1.44 gm. while one litre of air weighs 1.29 gm. It does not burn, but it supports combustion better than air. It is slightly soluble in water, and all natural waters contain oxygen dissolved in them, though the amount can never, under ordinary circumstances, exceed about 3 per cent. Yet on this small proportion of dissolved oxygen, fish and other marine organisms depend for the maintenance of life.

Oxidation.

The most important chemical property of oxygen is its power of uniting with other elements forming *oxides*. An oxide is a compound of two elements, one of which is oxygen. When a substance combines with oxygen, it is

said to have been *oxidised*; the process of depriving a compound of its oxygen is called *reduction*. Thus mercury, when it is heated to about 350°C ., is oxidised to mercuric oxide, and mercuric oxide when more strongly heated is reduced to mercury.

In some cases, oxidation takes place at the ordinary temperature; for example, when dry phosphorus is exposed to the air, white fumes are immediately given off which consist of phosphorus pentoxide. It is nearly always necessary, however, to heat the substance before oxidation takes place. In every case where a substance oxidises in the air either with or without the help of heat, it does so much more rapidly in pure oxygen. Phosphorus, which oxidises slowly in air spontaneously, and which burns rapidly on the application of a little heat, burns with great brilliance in oxygen, producing dense white fumes of phosphorus pentoxide. Iron, which rusts very slowly in air, can be made to burn quickly in oxygen, if it is in the form of *fine wire*. Magnesium burns with a brilliant flame in air, but when it burns in oxygen the flame is of dazzling brightness.

Classes of Oxides.

Of the oxides of the above mentioned three elements, phosphorus, iron, and magnesium, the first and last are soluble in water, while iron oxide is insoluble in water. If to these oxides, or their aqueous solutions, is added some litmus (a dye obtained from lichens), different results will be obtained in each case. The solution of phosphorus pentoxide will turn the litmus to a bright red colour, the solution of magnesium oxide will turn it blue, while the iron oxide will cause no change in colour. Oxides may be divided into three classes, according to their action on litmus: (1) Oxides which turn litmus red; (2) oxides which turn litmus blue; (3) oxides which do not affect

litmus. If a large number of oxides are tested in this manner, and the oxides in each class compared, it will be found that all those in the first class have one fact in common, namely, they are all oxides of a non-metal; the oxides in the other two classes are oxides of metals. The solutions of the oxides of the non-metals in water have a sour taste, and are called *acids*; the oxides of the metals are called *basic* oxides, and those of them that are soluble

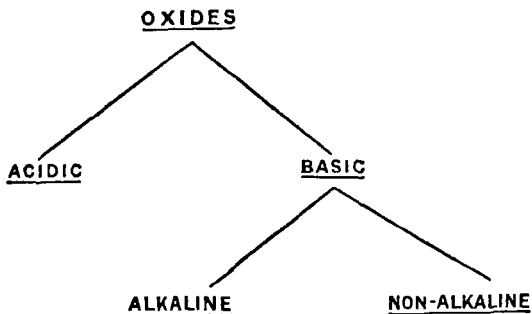


FIG. 8.—Classification of Oxides.

in water and turn litmus blue are called *alkalies*. Note in passing that the word "oxygen" means "acid producer." Lavoisier, who gave the gas its name, thought that oxygen was a necessary constituent of all acids, but it was discovered later that this was not the case, a few acids being known which contain no oxygen. The name, therefore, does not truly represent the facts. The peculiar property of litmus by which it may be used to indicate the presence of an acid or an alkali was discovered by Robert Boyle.

CHAPTER IX

THE AIR AND ITS CONSTITUENTS— (3) NITROGEN AND THE RARE GASES

Properties of Nitrogen.

The proportion of nitrogen in the air by volume is 78.03 per cent. Its chief function is to dilute the oxygen, for oxygen alone would cause all combustion to proceed too rapidly. One peculiarity about nitrogen is that its properties are mainly negative, that is, it is distinguished from other gases by the things it will *not* do: it is a chemically inactive gas under ordinary conditions. Nitrogen seems to have been first clearly recognised by an Edinburgh scientist, Dr. Rutherford. Cavendish called it *phlogisticated air* because he thought it was air saturated with phlogiston. Lavoisier called it *azote* (without life) because he found that it was incapable of supporting life. Its modern name nitrogen (nitre-maker) was given to it later when it was discovered that it was one of the elements present in nitre.

Preparation of Nitrogen.

There are two general methods of preparing nitrogen. The first is to remove oxygen from the air by means of a suitable element such as phosphorus which will combine with the oxygen and leave the nitrogen. The nitrogen obtained by this method is not pure, however, as will be explained below. The second method is to prepare it from one of its compounds, for example, nitre. As stated above, its properties are mainly negative; it has no colour, no smell, no taste, it does not burn, it does not

support combustion or life. It is slightly less dense than air, as would be expected since oxygen is more dense than air.

Nitrogen necessary for Plant Life.

Commercially, the preparation of certain compounds of nitrogen is very important. Nitrogen plays a large and essential part in the life of plants, but, in spite of the fact that there is a boundless store of nitrogen in the air, most plants are incapable of drawing directly on this store for their necessary supplies ; they must get it in combination with something else. Plants receive the nitrogen they require through their roots in the form of compounds of nitrogen called nitrates which are dissolved by rain, and so pass easily into the plants.

Carbon Dioxide.

The third constituent of the air is carbon dioxide, or, to give it its popular and inaccurate name, carbonic acid gas, which constitutes 0.03 per cent. of the air. As this gas will be fully dealt with in Chapters XI. and XII., we shall omit any further reference to it here.

A Residue not accounted for.

In the year 1785, Cavendish in the course of his experiments on air obtained a result which puzzled him. When he had removed by suitable means all the oxygen, nitrogen, and carbon dioxide from the air, a very small quantity of gas remained. This experiment seemed to him to indicate that there was something else in the air besides the three gases he had removed, but the knowledge possessed by Cavendish and the means at his disposal did not permit him to investigate the matter any further.

Rayleigh's delicate Experiment.

We hear no more about this curious result of Cavendish's experiment for more than a century, when, in 1892, it cropped up again in a different manner. Lord Rayleigh,

who was at that time Professor of Natural Philosophy in the Royal Institution, London, was carrying out a series of exceedingly accurate experiments with the object of finding the exact densities of the common gases. In the case of nitrogen, he prepared the gas in two ways: first, from the air, and secondly from one of its compounds. He found that there was a small difference in the density of the gas obtained by these different methods; one litre of atmospheric nitrogen weighed 1·25718 gm., while one litre of nitrogen from one of its compounds weighed 1·25107 gm. The fact that the weight is given to five decimal places indicates the extreme accuracy with which the experiment was carried out. There was a difference then of 0·00611 gm. to be accounted for. It was a very small difference, amounting to only 0·5 per cent., but it was too large, as Rayleigh could prove, to be due to experimental error. He repeated the whole experiment, this time preparing nitrogen from a different compound. The result was exactly the same as before. Nitrogen obtained from any of its compounds had always the same density; that obtained from the air had always a slightly greater density. Rayleigh concluded that atmospheric nitrogen was not pure nitrogen, but had some denser gas mixed with it.

Ramsay's Confirmation.

Another chemist, Sir William Ramsay, who was Professor of Chemistry in University College, London, now interested himself in the matter. He took a large quantity of atmospheric nitrogen and heated magnesium in it. The nitrogen combined with the magnesium forming a compound called magnesium nitride, but a gas remained which could not be made to combine with the magnesium. This gas he found to have a greater density than nitrogen, one litre of it weighing 1·7815 gm.

Argon.

Rayleigh and Ramsay next repeated Cavendish's forgotten experiment, but with much more care, and with greatly improved apparatus, and they obtained the same result as Cavendish did, namely, that after all the oxygen, nitrogen, and carbon dioxide were accounted for, there was a residue which had not previously been investigated. They laboriously collected a large quantity of this residue, examined its properties, and were able to announce in 1894 that they had discovered a new gas which they called *argon*, from a Greek word meaning lazy, because the gas is chemically inactive. This gas, they said, constitutes about 1 per cent. of the air.

Helium.

As far back as 1868, it was discovered that there was an element in the sun which, as far as was then known, did not exist on the earth. How, it may be asked, do we know what elements are in the sun, which is more than ninety million miles away? It is one of the marvels of modern science that we do know the composition of the sun, and even of the stars. The instrument which makes this possible is called a spectroscope, but it would take too long to describe it here. It was by means of this instrument that it was discovered that, in the sun's atmosphere, there was a gas which was unknown. This gas was named *helium*, from the Greek word meaning the sun.

It was Sir William Ramsay who first showed that helium existed in the air, being part of the 1 per cent. which had been considered to be argon. Helium has been brought to the notice of chemists in recent years, because it has been found that certain metals such as radium are constantly giving off small particles of helium. It has also been familiarised to the public because it has been suggested that helium is more suitable than hydrogen or coal-

gas for use in balloons and airships. It is twice as heavy as hydrogen ; but it is still seven times lighter than air, and besides, it is not inflammable, as hydrogen is, hence its use would minimise the risk of balloons and airships catching fire either accidentally, or owing to an enemy's incendiary bullets.

Neon, Krypton, and Xenon.

Even now we have not come to the end of the atmospheric gases. Ramsay, assisted by another chemist, as a result of a series of extremely accurate and refined experiments, discovered no less than three more gases in the air, which were named *neon* (new), *krypton* (concealed), and *xenon* (the stranger) respectively. When it is remembered that these three gases, along with argon and helium, constitute less than 1 per cent. of the air, it will be realised that the experiments by which they were discovered must have been conducted with a patience and accuracy that can only be described as marvellous. It gives an impressive indication of the great progress that has been made during the last century in experimental method.

Composition of Air.

Besides the gases above mentioned, there are variable quantities of water vapour in the air which account for the variation in the height of the barometer. The composition of dry air is shown by the following table :

Nitrogen	.	.	.	78·03 per cent.
Oxygen	.	.	.	20·99 „
Carbon dioxide	.	.	.	·03 „
Argon	}	.	.	·95 „
Helium				
Neon				
Krypton				
Xenon				

CHAPTER X

HYDROGEN AND WATER

Discovery of Hydrogen.

The first man, as far as we know, to prepare hydrogen was Paracelsus at the beginning of the sixteenth century. He noticed that when iron was treated with an acid in water, an inflammable gas was evolved. One would think that the novelty of a gas that burned would have induced him to try to find out more about it, but, beyond noting that it was inflammable, he does not appear to have studied its properties. Boyle in the seventeenth century produced hydrogen by dropping iron nails into dilute sulphuric acid, but he too did not pursue the subject, in fact he attached no importance to it, considering that this was merely a method of producing artificial air.

Macquer burns Hydrogen at a Jet.

The first chemist who made a real attempt to study this inflammable gas was Pierre Joseph Macquer who was born in Paris in 1718. He is said to have been of Scottish origin, as his surname might indicate. He prepared hydrogen by treating zinc with dilute sulphuric acid, and led the evolved gas along a tube which terminated in a jet. Having made certain that all the air had been expelled from the apparatus, he lit the hydrogen as it issued from the jet. Let us now give his own words as to what he did next : " I also assured myself by placing a white porcelain saucer in the flame of the inflammable gas which was burning quietly at the mouth of a bottle that the flame was accom-

panied by no smoke, for the part of the saucer touched by the flame remained particularly white, only it was wetted with drops of a liquid like water which indeed appeared to me to be nothing else than pure water." Unfortunately Macquer gave no proof that the liquid was water, nor did he give any explanation as to how it came about that water was formed. It must be remembered, however, that at this time oxygen had not been discovered, nor had all

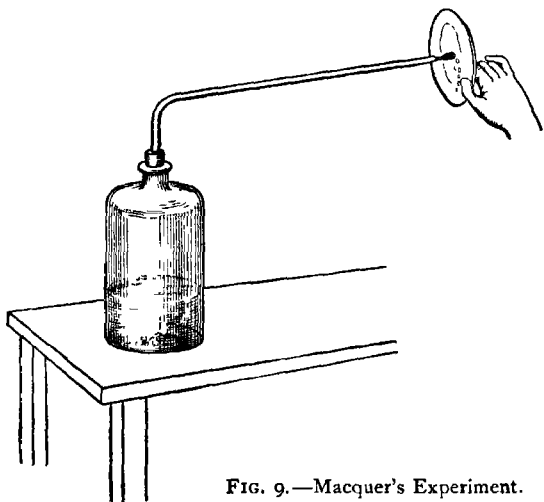


FIG. 9.—Macquer's Experiment.

the facts about combustion been brought to light; in fact, Macquer died just about the time that Lavoisier announced his oxygen theory of combustion. Macquer, therefore, did not have the necessary information to enable him to realise the result of his experiment. As it happened, his guess was correct, as was proved later.

Henry Cavendish.

Although hydrogen was really discovered by Paracelsus in the first half of the sixteenth century, its properties

were not systematically investigated until the year 1766. About that year, the matter was taken up by one of the outstanding men of the eighteenth century, the Honourable Henry Cavendish. This distinguished Englishman, who lived at the same time as Priestley, was, in his personal characteristics, very different from his compatriot. While Priestley was in poor circumstances, and had to earn his own living, Cavendish was a man of wealth. Priestley was friendly and sociable; Cavendish was of a retiring disposition, and almost a hermit. Priestley studied chemistry qualitatively, that is, without, as a rule, measuring the weights or volumes of the substances used in his experiments; Cavendish's experiments were nearly all quantitative. They resembled each other, however, in the great zeal with which they studied science. Their zeal was rewarded, too, for each made an important discovery which has made his name famous in the history of science.

Henry Cavendish was the son of Lord Charles Cavendish who, though he cannot be called a noted scientist, had a taste for scientific pursuits, which was inherited by his son. At an early age Henry Cavendish began to devote himself to science, and ultimately he made it his life-work. He was enabled to do this by the fact that he unexpectedly came into the possession of a large fortune, which, however, did not alter the simple habits he had acquired in his younger days. Some strange stories are told about his eccentricities. It is said that his servants were instructed to keep out of his sight, otherwise they would be dismissed on the spot. In order to avoid speaking to any of his servants, he ordered his dinner by leaving a note on the hall-table. He was not a snob, but simply preferred his own company to that of others. The keynote of his work was accuracy and attention to details. His investigations covered a wide range of subjects, and he contributed in no small measure to the progress of

science, though, as we shall see, he was bound by the phlogiston theory, and it was left to others to interpret his work in the modern way. In this respect the careers of Cavendish and Priestley are very similar, and in both cases it was Lavoisier who put the finishing touches to their work.

Water one of the Greek "Elements."

Cavendish rediscovered hydrogen, and made a close and careful study of its properties, but this work was only preliminary to an even more important discovery, namely, the composition of water. Water was one of the "elements" of the ancient Greeks, and, up to the eighteenth century, it was considered to be a simple substance, incapable of being decomposed into other substances. Nothing, of course, was more natural. Water is everywhere in evidence on the earth, and in nature water is never decomposed. Even now, to any one who does not know the facts, there is nothing to indicate that water is not a simple substance. It requires the patient and persevering work of the scientist to reveal the wonders of Nature, which become more and more wonderful the deeper we probe into her secrets. It is not only the poet who finds "sermons in stones." It has been said that "each chemical experiment is a question put to nature," and Nature's answers to some of the questions put to her are indeed startling. The answer to the question we are now considering, namely, What is the composition of water? was so surprising that many at first refused to believe it.

Priestley entertains some Friends.

Cavendish found out while experimenting with hydrogen that, not only did the gas burn, but that a mixture of hydrogen and air exploded when a light was put to it. Priestley, who had learned of this new "air" that Cavendish

had obtained, repeated the latter's experiments, and was very fond of exploding mixtures of hydrogen and air for the amusement of his friends. On one occasion he was thus entertaining some friends when one of them, John Waltire by name, drew his attention to the fact that, although the globe containing the mixture of gases was dry at first, after the explosion had taken place, the inside of the globe was damp. Priestley seems to have thought that the presence of this moisture was accidental, at any rate he did not follow up the clue that was presented to him. If he had done so, he might have deprived Cavendish of the distinction of being the discoverer of the composition of water.

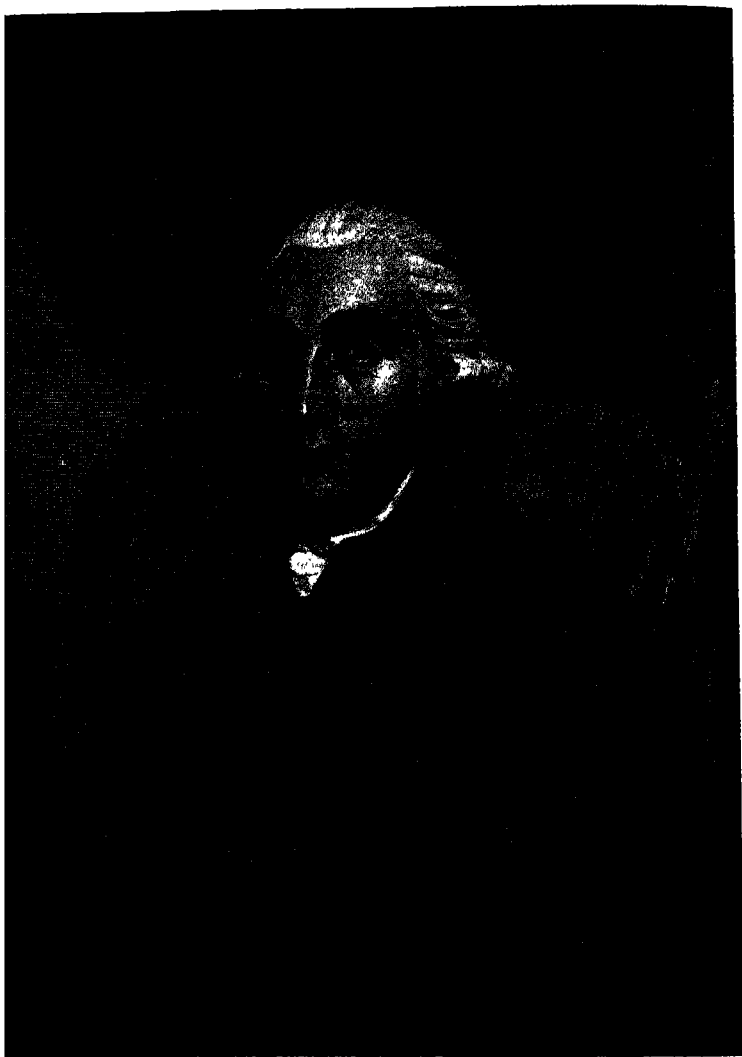
Cavendish follows up the Clue.

Cavendish was a more skilled experimenter than Priestley, and had a greater regard for details. He saw the moisture that had been pointed out by Waltire, but did not neglect it as being of no account. In a carefully-arranged series of experiments, he exploded mixtures of hydrogen and air in different measured proportions, and arrived at the result that when a mixture of hydrogen with two and a half times its volume of air was exploded, all the hydrogen and about one-fifth of the air "condensed to dew." Similarly, he showed that when a mixture of hydrogen with half its volume of oxygen was exploded, no gas was left at all, but only some moisture. The next task he set to work on was to try to find out what the "dew" was. Using an electric spark, he exploded a mixture of hydrogen and air in a closed globe, and repeated the process several times in the same globe, until he had obtained a quantity of the liquid sufficient to allow him to test its properties. The liquid, he found, had no taste, no smell, when evaporated left no residue, and in no respect did it differ from water; hence he concluded that it was pure water.



THE HON. HENRY CAVENDISH, F.R.S.

From a drawing by William Alexander in the British Museum.



Professor JOSEPH BLACK, M.D.

From the engraving by C. Cook, after the painting by Sir Henry Raeburn.

Cavendish's Explanation.

Let us now see what was in Cavendish's mind all this time—how he explained his results. In the first place, he considered that the gas we now call hydrogen (it did not receive this name till later) was nearly pure phlogiston, and that this phlogiston was set free from a metal by the action of dilute sulphuric or dilute hydrochloric acid. As a result of the above experiments, however, he changed his mind, and now thought that the gas was a compound of phlogiston and water. When he exploded a mixture of hydrogen and air, he thought that the phlogiston from the hydrogen combined with the air, producing "phlogisticated air" (nitrogen), and left water. It did not seem to occur to him that the water might be formed by the combination of "inflammable air" and "dephlogisticated air." That was too simple, and besides, it left out phlogiston !

Lavoisier to the Rescue.

While Cavendish, Priestley, and others were trying to fit the many recently discovered facts into the phlogiston theory, Lavoisier heard of Cavendish's experiments, and repeated them. As usual, his alert and comprehensive mind realised their significance, and he had no hesitation in saying that they proved that water was a compound of hydrogen and oxygen. He not only proved it, as Cavendish had done, by *synthesis*, that is, by the formation of the compound, water, directly from its elements, hydrogen and oxygen, but also by *analysis*, that is, the decomposition of water into its elements. For the latter process, he passed steam over red-hot iron wire, and collected hydrogen, while iron oxide remained. He proved that it was iron oxide by comparing it with the substance he obtained by burning iron in oxygen. Both methods led to the same conclusion, and one would think that nothing could be more convincing, but Cavendish,

like Priestley, would not give up the phlogiston theory, preferring rather to give up chemistry altogether than to abandon the beliefs on which all his work had been based. It was Priestley's discovery of oxygen that, in the hands of Lavoisier, began the downfall of the phlogiston theory, and it was Cavendish's experiments that sounded its death knell, yet both these men, along with others, whether because of national jealousy or natural conservatism,

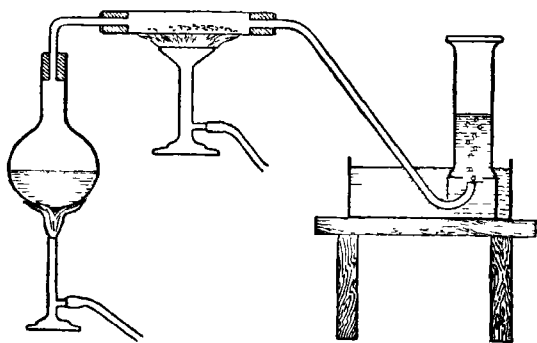


FIG. 10.—Passing Steam over Red-hot Iron Filings.

would not give it up, and died without being converted to the new beliefs.

Preparation and Properties of Hydrogen.

Hydrogen may be easily prepared in small quantities in a variety of ways, for example, by the action of sodium and potassium on water, by burning magnesium in steam, or by passing steam over red-hot iron filings (Lavoisier's experiment), but it is generally prepared by the action of zinc on dilute sulphuric acid. The name hydrogen, meaning "water-producer," was given to it by Lavoisier. It is a colourless and odourless gas. It burns with a pale blue almost invisible flame, but it does not support combustion. A mixture of hydrogen and air or hydrogen and oxygen explodes when heated, the cause of the explosion being

the sudden expansion due to the intense heat generated by the chemical action. It is the lightest substance known, its density being 0.09 gm. per litre, which is about one-fourteenth of the density of air. The extreme lightness of hydrogen is made use of in balloons. In 1783 in Paris, the first ascent was made in a balloon filled with hydrogen. Later, it was found that coal-gas, though only half as dense as air, was nearly as good as hydrogen for this purpose, and it was less expensive. Coal-gas owes its low density to the fact that it contains about 50 per cent. of hydrogen.

When a kettle of cold water is set on a gas ring to heat, drops of water form on the bottom of the kettle. Where does this water come from? The fact that coal-gas contains hydrogen supplies the answer to that question. The hydrogen, burning in air, combines with oxygen, forming water in the form of vapour which condenses on coming in contact with the cold kettle. When the kettle becomes warm, the vapour escapes without condensation.

When hydrogen burns in air, the flame is a very hot one, but if a jet of oxygen is directed on the burning hydrogen, an intensely hot flame is produced. The temperature of the oxy-hydrogen flame is so great (2800°C.) that platinum is melted by it. Limelight is produced by placing a cylinder of lime in either an oxy-hydrogen flame or an oxy-coal-gas flame (coal-gas contains about 50 per cent. of hydrogen). Lime does not melt even at that high temperature, but it becomes white hot, and emits a brilliant white light.

Water a Compound.

Since water consists of two gases, hydrogen and oxygen, it cannot be an element, as was supposed up to the eighteenth century. Is it a mixture? It is obvious that it cannot be a mixture, because its properties are totally different from those of its constituents. Hydrogen and oxygen may be mixed without producing water, in the same way as oxygen and nitrogen are mixed in the air ;

but whenever the temperature of the mixture of hydrogen and oxygen is raised to a certain point, the gases combine chemically with the evolution of heat, forming an entirely different substance, water, and losing all their original properties. Water is therefore a chemical compound, hydrogen oxide, and its constituents cannot be separated by any physical means. The proportions of hydrogen and oxygen in water are always exactly the same, namely, two parts by volume of hydrogen to one part by volume of oxygen, or, one part by weight of hydrogen to eight parts by weight of oxygen.

Diffusion.

Despite the fact that hydrogen has such a low density, it can mix *downwards* with other gases. If a jar containing hydrogen is left mouth downwards for a few minutes, the hydrogen will escape, even though it is so much lighter than air. This property which all gases possess of mixing with one another irrespective of their densities is called *diffusion*.

Combustible and Supporter of Combustion.

It has been stated that oxygen does not burn, but is a supporter of combustion, and that hydrogen burns but does not support combustion. This is true under ordinary circumstances, but matters may be so arranged that oxygen burns in hydrogen. The terms combustible and supporter of combustion are only relative terms. As commonly used, they refer to ordinary conditions.

Occurrence of Water.

An examination of the map of the world reveals the fact that there is a greater proportion of water than of land on the earth's surface. A rough estimate shows that five-sevenths is covered with water in seas, rivers, and lakes. Besides this large amount in the free state, water is also found associated with other substances ; for example,

plants are largely composed of water, and our own bodies contain water to the extent of about 70 per cent. It also occurs as water of crystallisation which is necessary for the formation of some crystals.

Essential for Life.

Water, like air, is indispensable for the maintenance of plant and animal life. If the world were suddenly deprived of water, life would in a few weeks become non-existent. Not only is water necessary for food, but it is also essential for cleanliness. The amount of water used daily in the interests of cleanliness is enormous, and in time of drought, when economy of water is enforced, the inconvenience experienced makes us realise how much we depend on a plentiful supply of water.

Water as a Solvent.

Water has also an interest and a practical importance because it has the power of dissolving other substances, and many operations in the chemical laboratory make use of this property. Many substances, however, do not dissolve in water, and the difference in solubility of different substances is sometimes made use of to separate one from another. Suppose, for instance, that, after having prepared oxygen by heating a mixture of potassium chlorate and manganese dioxide, it is desired to recover separately the potassium chloride and manganese dioxide remaining in the vessel. When it is known that potassium chloride is soluble in water while manganese dioxide is insoluble, it is only necessary to shake up the mixture with water and filter to separate the two substances. The potassium chloride will pass through the filter paper in solution, and may be recovered by evaporating off the water; the manganese dioxide will be left on the filter paper.

How Salt is obtained.

It is a commonplace that sea water has a salt taste, for it contains common salt and other substances dissolved

in it. The solid matter may be obtained from sea water by the simple process of allowing the water to evaporate, and this is done commercially. Sea water is pumped into large shallow pans, and left there till the water has evaporated, or it is boiled to drive off the water, the latter being a more rapid but more expensive method. In Cheshire, where there are extensive salt-beds, the salt in some cases is mined like coal, but in some parts of the county it is obtained by a different process. A hole is bored through the earth and rocks until the salt-bed is reached ; water is then poured into the hole, and, after being allowed to remain in contact with the salt for some time in order that it may dissolve some of it, the brine is then pumped up to the surface, and evaporated to dryness in shallow pans.

Spring Water.

Many springs contain dissolved solids that have value as medicines. Where such springs occur, towns have sprung up which are visited by certain people in search of health. In some cases, the springs are hot ; for example, those at Bath have a temperature of about 50° C. It is of interest to note that these springs were used by the Romans nearly two thousand years ago, as is shown by the remains of their bathing-places which may still be seen. The springs contain as many as ten different substances in solution, most of which have a distinctly curative value.

The Alkahest.

One of the hopeless tasks which the alchemists set themselves was to find a substance that would be a universal solvent, that is, a liquid that would dissolve any solid. They called it the *alkahest*. It did not seem to strike them that they would not be able to keep it when they found it, for, seeing that it would dissolve all substances, it would dissolve any vessel into which it was put. The alkahest, like the philosopher's stone and the *elixir vitæ*, was a product of the imagination.

CHAPTER XI

JOSEPH BLACK

Van Helmont discovers a New Gas.

Mention was made in Chapter IX. of carbon dioxide as a constituent of the air. It must now be studied more fully. Van Helmont, whose name has been mentioned more than once in the preceding pages, occupies a worthy place in the history of chemistry, for he was the first to draw attention to gases, and introduced the word "gas," though later chemists adhered to the word "air," to describe any gas. Before his times gases had escaped the notice of experimenters, principally because of their invisibility. One of the gases which Van Helmont distinguished was carbon dioxide, which he called *gas sylvestre* (that is, wood-gas). He showed that it was produced by the combustion of wood charcoal in air, but he thought that the gas was contained *in* the charcoal, and that the heat liberated it. He obtained the gas also by treating shells with an acid, and pointed out that it was present in mines and caves, and in certain mineral waters.

The Discovery forgotten.

The work of Van Helmont in this connection was forgotten by chemists, and it is not till the middle of the eighteenth century that we again hear about carbon dioxide. It is rather remarkable that so many of the discoveries of the older chemists were not followed up immediately. Though hydrogen was discovered by Paracelsus early in the sixteenth century, it was left for

Cavendish two and a half centuries later to investigate the gas fully. Though Hooke and Mayow showed that only a part of the air was concerned in burning, it was a hundred years before the full meaning of combustion was revealed. Progress had to wait for skilled experimenters like Black and Cavendish, or an acute mind like Lavoisier's.

Joseph Black.

Carbon dioxide was rediscovered by Joseph Black who was born at Bordeaux in 1728. His parents were of Scottish descent, and, on their removal to Scotland, Joseph entered Glasgow University when he was sixteen years of age. He developed a liking and aptitude for chemistry, and he was ultimately appointed assistant to the Professor of Chemistry, Dr. Cullen. He had chosen, however, the profession of medicine for his future career, and, to complete his training, he had to go to Edinburgh which has always been noted for its medical college. While he was studying at Edinburgh, he heard discussions between two medical professors as to whether lime-water prepared from oyster shells by heating, or that made with ordinary lime from limestone was the better medicine. These discussions made him determine to investigate the matter for himself, which he did with far-reaching results for chemistry.

Black's Experiments on Limestone.

Black's researches cleared up many misconceptions that prevailed at the time. One of these was that when limestone was "burned," that is, heated, it took up phlogiston (some said that it took up heat, or "fire-stuff"). Now Black heated limestone, and, in the truly scientific manner, weighed it before and after heating. He was surprised to find that there was a loss in weight, from which fact only one conclusion could be drawn, namely, that the limestone had lost something instead of gaining

something. He noticed also that when an acid was added to limestone an effervescence took place, while no such action followed an addition of acid to lime, the residue after limestone has been heated.

Now what was escaping during this effervescence, and what was lost when limestone was heated? Black asked himself. He sought the answers to these questions by a careful series of experiments, and he found the answers in the year 1757. The effervescence was caused by the escape of a gas, and the same gas was given off when lime-

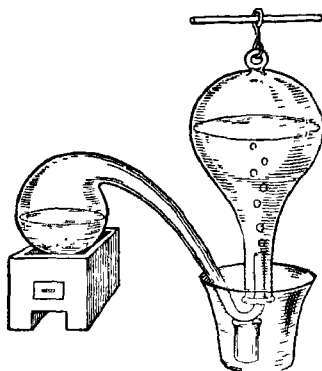


FIG. 11.—Apparatus devised by Stephen Hales for collecting Gases.

stone was heated. This was the gas we now call carbon dioxide or carbonic acid gas.

Black put some limestone into a retort along with a little dilute acid, and collected the evolved gas in a bottle filled with water. He used some such apparatus as is shown in Fig. 11, which it will be seen is a crude form of pneumatic trough, which had been devised a few years previously by a man called Stephen Hales. (It was several years after this that Priestley gave the pneumatic trough its modern form.) Black called the gas that filled the bottle "fixed air," because it had been fixed in the limestone.

Later, Lavoisier gave it the name carbonic acid gas, by which it is still popularly but incorrectly known.

Black also discovered the fact that lime-water became turbid when it was shaken up with fixed air, and used this property, as it has been used ever since, as a characteristic test for the gas. By means of lime-water, he proved that carbon dioxide was present in the air, and also that we breathe out the gas. He showed also that animals could not survive longer than a few seconds in an atmosphere of carbon dioxide.

Black, the Pioneer of Progress.

Although he lived to the age of seventy-one, Black completed all his original work before he was thirty-four years old. The remainder of his life was devoted to perfecting his course of lectures at Edinburgh University. He left others to explore fully the regions he had opened up both in physics and in chemistry, for, in addition to his work in chemistry at Edinburgh, he discovered latent and specific heat while he was in Glasgow. He died in 1799 as he sat at meat, without a moment's illness, and so peacefully that his servant supposed that he had fallen asleep.

Although Black's discovery of "fixed air" has been recorded after the work of Priestley, Cavendish, and Lavoisier, in point of time it took place before the discoveries of these chemists, and it is doubtful if they would have progressed so far in chemistry had they not been preceded by Black. Priestley's interest in the subject was aroused by the fact that, about 1770, he was living near a brewery in Leeds. In processes of fermentation such as occur in the manufacture of alcoholic liquors, carbon dioxide is given off, and so Priestley was able to obtain as much "fixed air" as he wanted for experimental purposes. One of his suggestions in this connection was that "fixed air" dissolved in water under pressure might be used as a cure for scurvy. Such a solution is now sold under the

name of "soda water." Cavendish's introduction to chemistry was also by way of "fixed air." He took up the study of this gas where Black left off, and studied its properties in his usual thorough manner. Lavoisier repeated the experiments of his contemporaries (sometimes unscrupulously passing them off as original), and determined the composition of the gas by burning carbon in oxygen. He also found that the solution of the gas in water acted like an acid, hence his name for the gas.

Considering the large amount of work which followed Black's discovery, we may regard him as the pioneer of progress in this remarkable century. His constant appeal to the balance, his carefully conducted experiments, set an example to others from which they could hardly fail to profit. Had his health permitted him to continue his researches, chemistry would have gained considerably more than it actually did by his labours. Although he was not himself engaged in original investigations, he kept in close touch with the work of the leading chemists both in Britain and in Europe, and, when Lavoisier announced his new theory of combustion, Black was the only British chemist of any standing to accept it at once. He was not so bound up in the phlogiston theory that he could not see the force of Lavoisier's logic supported by such an array of facts.

CHAPTER XII

CARBON DIOXIDE

Carbon.

Carbon is an element which is very widely distributed in nature. It exists in a more or less pure state in charcoal, coal, and coke, and it is an essential constituent of plants and animals. It can exist in three forms, in which its properties differ in almost every respect; they are diamond, graphite, and charcoal in all its varieties. At first sight, the statement that a beautiful precious stone is composed of exactly the same material as soot seems ridiculous; nevertheless, such is indeed the case. The diamond was the subject of much speculation among the older scientists, but its true nature was not discovered till Lavoisier took the matter up. He showed that, when a diamond was burned in oxygen, the product of combustion was carbonic acid gas, which led him to the startling conclusion that the diamond was nothing else than pure carbon. Many attempts have been made to manufacture diamonds artificially, but, up to the present, only small stones commercially valueless have been produced.

Graphite is the substance which is used in the making of so-called "lead" pencils. It is not so pure as the diamond, containing about 5 per cent. of other substances.

Carbon is the chief constituent of coal, charcoal, and coke, but, in each case, it is associated with other substances which constitute the ash left after combustion.

The name "carbon" was introduced by Lavoisier, who,

it will be remarked, left his imprint on everything he took up. The charcoal he used in his experiments always left after combustion a certain amount of ash. When he wanted to speak about the pure substance he could not call it *charbon* (the French word for charcoal), so he modified the word and called it *carbone*, which became in English carbon.

Preparation and Properties of Carbon Dioxide.

When any form of carbon is burned in a plentiful supply of air, it combines with oxygen to form carbon dioxide. For experimental purposes, the gas is usually prepared by decomposing limestone or marble with a dilute acid. It is a colourless and odourless gas with a slightly sweet taste. At the ordinary temperature and pressure water dissolves its own volume of carbon dioxide, but it will take up more if the pressure is increased, which fact is made use of in the manufacture of aerated waters. It can be liquefied and even solidified with comparative ease. It is one and a half times heavier than air. It does not burn, nor does it support combustion or animal respiration, resembling nitrogen in these respects, and being distinguished from nitrogen by its action on lime-water. Although carbon dioxide does not support combustion under ordinary circumstances, the metal magnesium burns in it forming magnesium oxide and depositing carbon.

Respiration of Plants and Animals.

Carbon dioxide, as we have seen, is a constituent of the atmosphere to the extent of 0.03 per cent. Its presence there is easily accounted for by the fact that it is one of the products of combustion of every substance containing carbon, and that it is breathed out by all animals, including man. The reason why its proportion in the air is practically constant, however, is not so obvious. How is it that, in spite of all the carbon dioxide

that is poured into the air from factories, domestic fires, and the breathing of animals, the percentage of the gas in air varies only by a very small amount? The reason is that plants, under the action of sunlight, have the power of decomposing carbon dioxide, retaining the carbon and liberating the oxygen. This was discovered by Priestley in 1771, although, not having discovered oxygen yet, he could not explain what happened in his experiments. He knew that when a lighted candle was put into a closed space of air, it very soon went out, and that the remaining "air" did not support combustion or life. Priestley tested this "air" by placing a mouse in it, and found that the mouse soon died. He tried another experiment, however, the result of which caused him some surprise. He placed a sprig of mint in a closed vessel in which a candle had burned out. After ten days, he found that a candle could again burn in it. Further experiments with plants other than mint produced the same result. The explanation of these results was not forthcoming until after the discovery of oxygen and its corollary, the oxygen theory of combustion. It was then seen that the burning candle used up oxygen, forming carbon dioxide, and that the plant decomposed this gas, retaining the carbon to help its growth and setting free the oxygen for which it had no use. At night, or in a dark place, the reverse process takes place, the plant absorbing oxygen and giving off carbon dioxide. This is the reason why plants are generally removed from hospital wards at night. Public parks in towns not only provide pleasant places for recreation, but also serve the useful purpose of keeping the air pure, or at least less impure than it would be otherwise.

This process that goes on in plants is not fully understood. It has been discovered that only green plants act in this manner, which shows that the green colouring matter in these plants, called chlorophyll, plays some part in the process. The maintenance with almost mathematical

precision of the balance between oxygen and carbon dioxide is a good example of nature's simple and yet wonderful methods of providing for the inhabitants of the world. There is a saying which runs, "What is one man's food is another man's poison." We might alter it slightly to make it apply to the feeding of plants and respiration of animals, and say, "What is food to the plant is poison to the animal." Carbon dioxide, however, is not exactly a poison ; it is only harmful by excluding oxygen. It is a suffocating gas, not a poisonous one.

Carbon Dioxide in Coal-mines

Carbon dioxide is met with in coal-mines. It is formed by the slow oxidation of coal. Miners call it "choke damp." On account of its high density, it accumulates in the lowest parts of the workings, and especially in dis-used workings where it lies undisturbed.

—and in Caves and Chalk-pits.

The gas is also discharged in considerable quantities from volcanoes and fissures in the earth. In districts where chalk is quarried, tramps are occasionally found lying in chalk-pits dead. Carbon dioxide is slowly given off from chalk, and, being heavy, lies at the bottom of the pit. There is a cave near Naples called the *Grotto del Cane* or *Dog's Grotto* in which a dog cannot live, because of the accumulation of carbon dioxide. A man, however, can live in it because his head is above the level to which the suffocating gas reaches.

CHAPTER XIII

LIMESTONE

Formation of Chalk, Limestone, and Marble.

Chalk,¹ limestone, and marble are chemically identical. Chalk is found pure in many parts of the world, and in the South of England the chalk-beds attain considerable thickness. These beds were originally at the bottom of the sea, in fact they were formed there from the shells of tiny shellfish, each being so small that a microscope is necessary to see it. Limestone and marble have had the same origin as chalk ; they have attained their present form by being subjected to heat and pressure. In a previous age of the world's history, the earth's crust was not so stable as it now is. A particular portion of it was at the bottom of the sea at one time, and a few thousands of years later it appeared on the surface, while a further change buried it far in the earth. Changes such as these are responsible for the fact that coal is found far below the surface. We know that coal is all that remains of immense primeval forests which used to flourish on the earth ; a time of upheaval buried these forests, and in the course of ages they were transformed into coal. Chalk, therefore, originally formed in the ocean's depths, was transferred either to the surface or to the interior of the earth. The latter, by reason of the earth's internal heat, and the pressure of the rocks above it was gradually transformed into limestone. If the process was allowed to go further before the next upheaval took place, it was changed into

¹ Not blackboard chalk, which is an entirely different substance.



The Late SIR WILLIAM RAMSAY, F.R.S.



The late LORD RAYLEIGH, O.M., F.R.S.



[By courtesy of A. G. H. Gough, Esq.]
STALACTITES AND STALAGMITES IN GOUGH'S CAVES, CHEDDAR,
SOMERSET

marble. Limestone and marble are often coloured by other substances which are mixed with them, limestone being often yellow or brown, and marble having that characteristic veining which is sometimes very beautiful.

Early Use of Limestone and Marble.

It is difficult to say when these substances were first employed for building purposes ; it was certainly in very early times. In certain countries, such as India, marble has long been used in the building of temples, resulting in structures of wonderful beauty and great durability. The Romans, at the time of their invasion of Britain, used limestone in order to obtain lime by " burning " it, and though this process was carried on as far back as two thousand years ago, it was not, as we have seen, till the eighteenth century that what really happened during the " burning " was discovered by Black. The Latin word for lime is *calx*, from which it is evident that the alchemists considered that, when a metal was heated, the process was similar to the heating of limestone. We now know that they are quite different ; in the one case, oxygen unites with the metal, and in the other, carbon dioxide is driven off from the limestone.

Commercial production of Lime.

When limestone has been heated until all the carbon dioxide has been driven off, lime, sometimes called quick-lime, remains. The " burning " of limestone is carried out on a large scale in lime-kilns. A mixture of limestone and coal is placed in the kiln, which is a conical-shaped structure built of masonry cased with iron. A fire is lit at the bottom, and the flames soon spread to the coal above, rendering the limestone white-hot. After about two days, the lime and ash are withdrawn at the bottom, while more limestone mixed with coal is added at the top.

Discovery of Calcium.

For a long time it was thought that lime was an element. In 1789, Lavoisier published a list of the elements then known, and lime was one of them. No chemist had succeeded in decomposing it into anything else. In the year 1808, Sir Humphry Davy (the inventor of the Davy lamp) discovered a new element, calcium, by passing an electric current through the substance we now call calcium chloride after having melted it. He found that the new metal tarnished when left in the air. He burned it in oxygen and found that the calcium oxide so formed was identical in every respect with lime. Thus he proved that lime was not an element but a compound of calcium and oxygen. The compound formed by the combination of calcium oxide and carbon dioxide is calcium carbonate, or chalk. Any carbonate is a compound consisting of two oxides, one of which is carbon dioxide. By a process similar to that just described Davy discovered other metals including sodium, potassium, and magnesium.

Slaked Lime.

When quicklime is treated with a small quantity of water, it swells, cracks, and finally crumbles down into a dry powder. A large amount of heat is evolved, and this is a certain sign that a chemical change is taking place. The product of this action is called slaked lime, its chemical name being calcium hydroxide. It was this property of lime that caused it to be called quicklime (quick=alive, compare quicksilver). Slaked lime is the chief ingredient in mortar for building purposes. Quicklime is usually slaked on the spot, and the heat generated in the process is so great that clouds of steam are formed. After the mortar has been used to join the bricks or stones of the building, the water slowly evaporates, leaving the lime dry and hard. In course of time, carbon dioxide from the air combines with the lime, re-forming the limestone from

which the lime was originally obtained. The mortar therefore becomes harder than ever.

It is interesting to note that the purpose for which the Romans required lime was not building houses, but iron-mining. They bored a hole in the ground ; filled it with quicklime, and then poured in water. The lime slaked, and, in doing so, expanded, enlarging the hole. By repeating this process many times, they ultimately reached the iron ore.

Lime-water.

Slaked lime is slightly soluble in water, the solution being called lime-water, which, as has already been mentioned, is used for the detection of carbon dioxide. What happens is that the carbon dioxide combines with the lime, forming chalk, which, being insoluble in water, becomes suspended in the water in the form of very small particles. The large number of these tiny particles gives the cloudy or milky appearance to the liquid.

Hard and Soft Water.

If a constant stream of carbon dioxide is passed through lime-water, the milkiess that is caused at first ultimately disappears. The reason for this is that chalk dissolves in water in which carbon dioxide has been dissolved, although it does not dissolve in pure water. Now this apparently insignificant fact produces some results that are by no means insignificant. Rain, in falling through the air, dissolves a small quantity of carbon dioxide. When it reaches the ground, if it should happen to fall on chalk or limestone, the small amount of carbon dioxide in solution enables it to dissolve a little chalk or limestone. In limestone districts, the water that is supplied for domestic purposes is usually "hard," that is, it does not give a good lather with soap until a comparatively large amount of soap has been used. The "hardness" is caused by the presence in solution of chalk and other substances.

If the hardness of water is due only to the presence of chalk, it is easily removed by boiling. A gas is less soluble in hot water than in cold water, hence the carbon dioxide is driven out of solution, and when this happens, the water can no longer hold the chalk in solution which is therefore deposited on the bottom of the containing vessel. If the inside of a kettle that is used for boiling hard water be examined, this deposit of chalk, or "fur," as it is usually called, will be easily seen. The hardness that may be removed by boiling is called *temporary hardness*; when it is due to substances other than chalk, it cannot be removed by boiling; it is then called *permanent hardness*.

Stalactites and Stalagmites.

An interesting result of the fact that water charged with carbon dioxide is capable of dissolving chalk is the formation of stalactites and stalagmites in certain limestone caves. Rain-water, which always contains some dissolved carbon dioxide, when it falls on the ground immediately above a limestone cave dissolves some limestone in passing through from the ground to the cave. When it reaches the roof of the cave, a drop hangs there for a time, and then falls to the floor of the cave. While it is hanging, however, some of the water has time to evaporate, and some of the carbon dioxide goes with it, causing a small quantity of chalk to be deposited and left behind when the drop falls. This being repeated year after year, the deposits gradually grow larger, and, in course of time, an icicle-like pillar of chalk is formed depending from the roof of the cave. This is called a stalactite.

A somewhat similar effect is produced on the floor of the cave. Each drop of water after it falls loses more of its carbon dioxide, and therefore more chalk is thrown out of solution. In this way, a pillar, called a stalagmite, is gradually built up immediately below the stalactite, and if this goes on long enough, the two pillars ultimately meet.

REVISION QUESTIONS

THE AIR AND ITS CONSTITUENTS

1. How would you show that a part of the air is used up when iron rusts ?
2. Describe an experiment which shows that iron will not rust in the absence of water.
3. If a piece of bright iron is thrown into a stream it soon becomes rusty even if it is completely covered with water. Explain.
4. How would you show that the air consists of at least two different gases ?
5. Describe an experiment which shows what fraction of the air is used up when phosphorus burns.
6. Give a short account of Lavoisier's experiment with mercury, and state what conclusions may be drawn from it.
7. Give a short account of Priestley's discovery of oxygen. What name did he give to the gas ? Why ?
8. How did Scheele discover oxygen ? What did he call it ?
9. Account for the fact that the white powder formed when magnesium burns is heavier than the original magnesium.
10. Why is iron rust or phosphoric oxide not used to prepare oxygen ? Why is mercuric oxide not used when a large quantity of oxygen is required ?
11. Name the substances used to prepare oxygen in the laboratory. After all the oxygen has been driven off, what is left ?
12. How would you prepare a small quantity of oxygen from the air ?
13. Name and describe the substances formed when the following elements are burned in oxygen : phosphorus, magnesium, sulphur, iron, carbon, sodium.
14. What is an oxide ? Give two examples.

15. By what test may an acidic oxide be distinguished from a basic oxide ? Give an example of each class.
16. Into what two classes may basic oxides be divided ? Give an example of each.
17. Explain the term *oxidation*. What is the name of the opposite process ? Give examples.
18. How may nitrogen be obtained from the air ? Is the gas thus obtained pure ?
19. Write down a list of the constituents of dry air, giving their approximate proportions.
20. Is air a mixture or a compound ? Give reasons for your answer.
21. How would you prove that there is carbon dioxide in the air ?
22. Air is shaken up with water, then the gases are driven out of solution by heat and collected in a jar. How would you determine the composition of the contents of the jar ? State approximately what the composition would be.
23. Explain why the proportions of oxygen and nitrogen in the expelled air of the previous question are different from their proportions in ordinary air.
24. What use has recently been made of (a) helium, (b) neon ?
25. Describe what happens when liquid air is allowed to evaporate.
26. Describe an experiment which illustrates the fact that chemical compounds have a constant composition.
27. How may the manganese dioxide used in the preparation of oxygen be recovered ?
28. What is meant by the Indestructibility of Matter ? Describe an experiment which illustrates the truth of this law.
29. A piece of phosphorus is placed in a flask which is then tightly stoppered. The flask is heated till the phosphorus burns. What change in weight will occur (1) before, (2) after taking out the stopper ?
30. What is a tin can made of ? How do you know ?
31. What is a catalyst ? Name one.
32. How would you find the weight of oxygen in a room ?
33. Describe the consequences which would follow the sudden removal from the air of all the nitrogen.

34. Compare and contrast the rusting of iron, the burning of phosphorus, and the exploding of gunpowder.

WATER

35. Name all the methods you know by which a small quantity of hydrogen may be prepared. Describe the usual laboratory method. Why is this method preferred ?
36. Describe the metals sodium and potassium, and state what occurs when they come into contact with water.
37. When a piece of sodium is thrown on to water it melts. Where does the heat come from which causes it to melt ?
38. How would you obtain hydrogen from steam ?
39. How would you prove that water contains oxygen ?
40. How is it that a piece of burning magnesium when plunged into steam continues to burn, while a lighted taper is immediately extinguished ?
41. Is water an element, a compound, or a mixture ? Give reasons for your answer.
42. Five Winchester quart bottles contain respectively oxygen, nitrogen, carbon dioxide, sulphur dioxide, and hydrogen, but they are not labelled. If you were asked to label them correctly, how would you proceed to do so ?
43. How is it that water, which contains eight-ninths of its weight of oxygen, extinguishes fire ?
44. Salt disappears in water ; zinc disappears in dilute sulphuric acid. Are these two processes similar ? Give reasons.
45. How would you collect and identify the substance formed when hydrogen burns in air ?
46. Describe an experiment by which the composition of water by volume is found. How would you find its composition by weight ?
47. What is a reducing agent ? Name one.
48. Describe an experiment which shows that hydrogen is less dense than air.
49. What is the objection to the use of hydrogen in airships ? What other gas has recently been used instead of hydrogen ?

50. What is meant by diffusion ? Describe an experiment which shows this property of gases.
51. What is meant by the term *analysis* in chemistry ? What is the name of the opposite process ? Give one illustration of each.
52. What precaution would you take before lighting hydrogen at a jet ?
53. How could you obtain pure hydrogen from a mixture of hydrogen and oxygen ?
54. Lavoisier passed steam over red-hot iron wire. What did this experiment teach him about the composition of water ?
55. Describe and explain what happens when magnesium burns in steam.
56. What change in volume occurs when an electric spark is passed through a mixture of equal volumes of hydrogen and oxygen ?
57. When a kettle of cold water is placed on a lighted gas-ring, drops of a liquid appear on it. What is this liquid ? How does it come to be there ?
58. What are the products of combustion when a candle burns in air ? What do you infer as to the composition of the candle ?
59. Name the contents of a jar (originally containing air) in which a candle has burnt out.
60. How would you show that the jar in the previous question contains free oxygen ?
61. Phosphorus has been burnt in one jar and a candle in another ; how would you find out which jar had been used for phosphorus ?
62. Contrast the burning of a candle with the burning of hydrogen at a jet.
63. Explain how you could obtain a small quantity of hydrogen from a candle.

CHALK

64. What are the chemical names for *chalk*, *quicklime*, *slaked lime* ?
65. How would you prove that the gas given off when chalk is heated is the same as that given off when it is acted on by hydrochloric acid ?

66. In what respects are chalk, limestone, and marble similar ?
In what respects are they different ?
67. Into what substances is chalk decomposed by heat ?
68. Of what elements is quicklime composed ? How would you prove that it contains these elements ?
69. How would you prove that carbon dioxide is a compound of carbon and oxygen ? Give an analytic and a synthetic method.
70. Joseph Black called carbon dioxide *fixed air* ; can you suggest a reason for the name ?
71. How would you distinguish two white powders, one of which is chalk and the other quicklime ?
72. How is quicklime prepared commercially ?
73. How is slaked lime made ? How do you know that water does not merely mix with quicklime ?
74. Why are the walls of new houses always damp for a considerable time ?
75. What is lime water ? How do you account for the milkiness when carbon dioxide is passed into lime water ?
76. What is it that makes water in limestone districts " hard " ?
77. What is the name of the white substance which appears inside kettles used for boiling hard water ? How would you prove that it is what you say ? How does it come to be there ?
78. Describe the action of calcium on water.
79. Limestone is " burned " to obtain quicklime. Is this process similar chemically to the burning of coal ? Give reasons for your answer.
80. Slaked lime is a compound of quicklime and water. Account for the fact that slaked lime may be heated to a temperature higher than 100° C. without causing the water to evaporate.

GENERAL

81. Name and describe the substances formed when the following substances burn in air : (a) phosphorus ; (b) a candle ; (c) calcium ; (d) hydrogen ; (e) carbon.
82. Which of the following substances are oxides ? Water, air, chalk, quicklime, manganese dioxide, potassium chlorate, iron rust, slaked lime, mercury rust.

83. Classify the following substances into elements, compounds, or mixtures : iron, iron rust, gunpowder, brine, calcium, air, water, quicklime, chalk, carbon dioxide, mercury, phosphorus, sodium, potassium chlorate, oxygen, lime-water, hydrogen, limestone, mercury rust, manganese dioxide, zinc, slaked lime.
84. State which of the following changes are physical and which chemical, giving a reason in each case : (a) the freezing of water ; (b) the rusting of iron ; (c) the burning of a candle ; (d) the dissolving of sugar in tea ; (e) the burning of phosphorus ; (f) the slaking of lime ; (g) the electrolysis of water ; (h) the bursting of water pipes during frost.
85. In what respect does breathing resemble the burning of a candle ?
86. Describe what happens when magnesium burns (a) in air, (b) in steam, (c) in carbon dioxide.
87. Give examples of the use of the balance in furnishing a clue to the solution of a chemical problem.
88. The members of the Mount Everest Expedition of 1922 on one occasion inhaled oxygen to keep them warm. Explain how breathing cold oxygen made them warm.
89. Why did so many people die in the Black Hole of Calcutta ?
90. Carbon dioxide is breathed into the air by all men and animals, and it is produced when most ordinary combustibles burn. Account for the fact that the proportion of carbon dioxide in the air is practically constant.

NUMERICAL EXERCISES

THE AIR AND ITS CONSTITUENTS

1. A 250 c.c. flask when full of air weighs 102.512 grams, and when full of oxygen weighs 102.549 grams. If a litre of air weighs 1.29 grams, what is the weight of a litre of oxygen?
2. If the flask of the previous question weighs 102.504 grams when full of nitrogen, find the density of nitrogen.
3. Using the results of the last two questions, calculate the specific gravities of oxygen and nitrogen, taking air as the standard.
4. What volume of oxygen is contained in a room measuring 25 feet by 20 feet by 10 feet? If the specific gravity of oxygen (water as standard) is .00144, and a cubic foot of water weighs 1000 ounces, what is the weight of oxygen in the room?
5. 5 grams of moist iron filings are put into a 130 c.c. flask, which is then tightly stoppered. Of what will the contents of the flask consist after a few days? What will be the weight of gas left, and what will be the increase in weight of the iron? If the stopper is taken out of the flask when the neck is under water, how much water will enter the flask? (1 litre of oxygen weighs 1.44 grams, 1 litre of nitrogen weighs 1.26 grams.)
6. If in Lavoisier's experiment with mercury the total volume of air enclosed was 5 litres, by how much would the mercury in the retort have increased in weight at the end of the experiment?
7. After 2.28 grams of potassium chlorate had been heated till no more oxygen was expelled, 1.39 grams of potassium chloride were left. Calculate the percentage of oxygen in potassium chlorate.
8. 10 grams of potassium chlorate are mixed with 3 grams of manganese dioxide, and the mixture is heated till no more oxygen is evolved. What substances will

- remain ? What weight of each could be recovered ? (Potassium chlorate contains 39.2 per cent. of its weight of oxygen.)
9. 8 grams of potassium chlorate and 2 grams of manganese dioxide are mixed and heated. What weight of oxygen will be evolved ? What will be the volume at N.T.P. of this quantity of oxygen ?
 10. How much potassium chlorate would be required to produce 5 litres of oxygen at N.T.P. ?
 11. On heating 4.25 grams of mercuric oxide till it was completely decomposed, 3.94 grams of mercury remained. Calculate the percentage of oxygen in mercuric oxide.
 12. What weight of mercuric oxide would be required to produce 5 litres of oxygen ? (Mercuric oxide contains 7.4 per cent. of its weight of oxygen.)
 13. Calculate the weight of a litre of air, given that a litre of nitrogen weighs 1.26 grams, and a litre of oxygen weighs 1.44 grams.
 14. 10 litres of air are slowly passed through a tube containing red-hot copper. What gas will be collected ? What will be the volume of this gas ? What will be its weight ? What will be left in the tube ?

WATER

15. 18 c.c. of hydrogen are passed into a eudiometer, then oxygen is passed in till the volume of the mixture is 30 c.c. The mixture is exploded and it is found that 3 c.c. of oxygen remain. Calculate the composition of water by volume.
16. A mixture of 250 c.c. of hydrogen and 100 c.c. of oxygen is exploded in a eudiometer. What gas will remain, and what will be its volume ? What weight of water will be formed ?
17. A mixture of 200 c.c. of hydrogen and 150 c.c. of air is exploded in a eudiometer. What gases will remain, and what will be their volumes ? What weight of water will be formed ?
18. What weight of water will be produced by the explosion of 300 c.c. of air and 100 c.c. of hydrogen ? What gases will be left, and what will be their volumes ?

NUMERICAL EXERCISES

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19. A 500 c.c. flask weighs 162.862 grams when full of air, and 162.261 grams when full of hydrogen. If a litre of air weighs 1.293 grams, calculate the density of hydrogen.
20. The density of hydrogen is 0.09 gram per litre, of oxygen 1.44 grams per litre, of nitrogen 1.26 grams per litre, and of air 1.29 grams per litre. Calculate the specific gravities of these gases, taking hydrogen as the standard.
21. Calculate the composition of water by weight, using data in the previous problem.
22. What weight of oxygen could be obtained from 45 c.c. of water at 4°C . ?
23. 5.4 grams of water were collected by burning hydrogen against a cold surface. Assuming that all the water vapour produced was condensed, what volume of hydrogen was burned, and what volume of oxygen used ?
24. What volumes of oxygen and hydrogen can be obtained by decomposing 9 grams of water ?
25. If 12 grams of magnesium combine with 8 grams of oxygen to form magnesium oxide, what weight of hydrogen will be set free by burning 0.3 gram of magnesium in steam ?
26. If 23 grams of sodium set free 1 gram of hydrogen from water, what weight of sodium would be required to produce 100 c.c. of hydrogen ?
27. If 50 c.c. of hydrogen are obtained by electrolysis of water, what weight of water has been decomposed ?
28. If 1 gram of hydrogen is evolved from a dilute acid by 32.5 grams of zinc, what weight of zinc would require to be used to produce 10 litres of hydrogen ?

CHALK

29. What weight of carbon dioxide can be expelled by strongly heating 0.5 gram of chalk ?
30. How much quicklime may be obtained from 5 tons of limestone ?
31. What weight of carbon dioxide would be required to change completely 2.5 grams of quicklime into chalk ?
32. What weight of carbon dioxide would be evolved by the

action of dilute hydrochloric acid on 2 grams of chalk ?

If the density of carbon dioxide is 1.98 grams per litre, what volume of carbon dioxide would be given off ?

33. What weight of chalk would be required to produce a litre of carbon dioxide ?
34. How much chalk would be produced by passing carbon dioxide into milk of lime containing 1.85 grams of slaked lime ?
35. How much chalk will be formed by passing carbon dioxide into 50 grams of lime water which contains $1\frac{1}{4}$ per cent. of its weight of slaked lime ?
36. What volume of carbon dioxide at 18° C. and 72 cm. pressure would you expect to be evolved from 100 grams of chalk ?
37. How much quicklime could be prepared starting with 2.8 grams of calcium ? How much slaked lime ? How much chalk ?
38. If 12 grams of magnesium combine with 8 grams of oxygen to form magnesium oxide, what weight of carbon will be deposited by burning 0.3 gram of magnesium in carbon dioxide ? (12 grams of carbon combine with 32 grams of oxygen to form carbon dioxide.)

ANSWERS TO NUMERICAL EXERCISES

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| <p>1. 1.438 gm.</p> <p>2. 1.258 gm. per lit.</p> <p>3. Oxygen 1.11.
Nitrogen 0.98.</p> <p>4. 1000 cub. ft.
90 lb.</p> <p>5. Iron rust and nitrogen.
0.13 gm.
0.037 gm.
26 c.c.</p> <p>6. 1.44 gm.</p> <p>7. 39.04.</p> <p>8. Potassium chloride 6.08
gm., and manganese
dioxide 3 gm.</p> <p>9. 3.136 gm.
2.18 lit.</p> <p>10. 18.37 gm.</p> <p>11. 7.29.</p> <p>12. 97.3 gm.</p> <p>13. 1.296 gm.</p> <p>14. Nitrogen.
8 lit.
10.08 gm.
Copper oxide.</p> <p>15. $H : O = 2 : 1$.</p> <p>16. 50 c.c. hydrogen.
0.162 gm.</p> <p>17. 120 c.c. nitrogen.
140 c.c. hydrogen.
0.0486 gm.</p> | <p>18. 0.081 gm.
240 c.c. nitrogen.
10 c.c. oxygen.</p> <p>19. 0.091 gm. per lit.</p> <p>20. Hydrogen . . . 1
Oxygen . . . 16
Nitrogen . . . 14
Air . . . 14.33</p> <p>21. $H : O = 1 : 8$.</p> <p>22. 40 gm.</p> <p>23. 6.67 lit. hydrogen.
3.33 lit. oxygen.</p> <p>24. 11.11 lit. hydrogen.
5.56 lit. oxygen.</p> <p>25. 0.025 gm.</p> <p>26. 0.207 gm.</p> <p>27. 0.0405 gm.</p> <p>28. 29.25 gm.</p> <p>29. 0.22 gm.</p> <p>30. 2.8 tons.</p> <p>31. 1.96 gm.</p> <p>32. 0.88 gm.
0.44 lit.</p> <p>33. 4.5 gm.</p> <p>34. 2.5 gm.</p> <p>35. 0.84 gm.</p> <p>36. 25 lit.</p> <p>37. 3.92 gm.
5.18 gm.
7 gm.</p> <p>38. 0.075 gm.</p> |
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